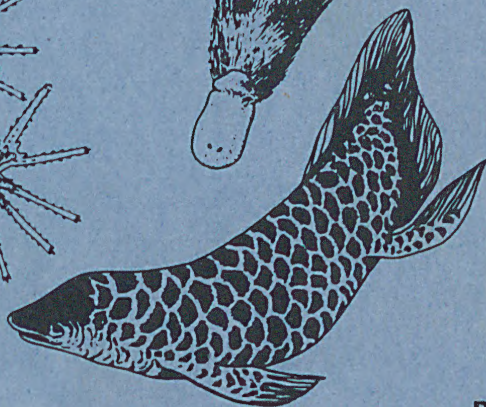
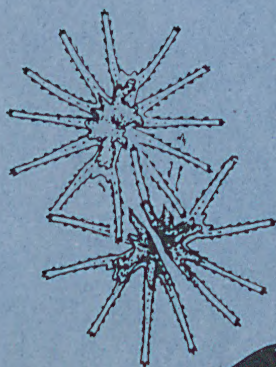
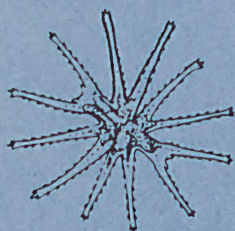


# Australian Society for Limnology



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**No. 10**  
December 1985



## NOTES TO AUTHORS

The *Bulletin* will accept for publication *original contributions*, subject to the following conditions:

1. Papers not directly related to Australia, New Zealand and New Guinea may not be accepted.
2. Taxonomic papers which describe new species will not be accepted unless any "type" material has been deposited at an Australian museum and evidence is presented of its Registration.
3. Manuscripts are to be typed, double-spaced and submitted in duplicate.
4. Photographs will be accepted only in exceptional circumstances.
5. Line drawings, graphs, etc., must be kept to a minimum.
6. All papers will be subject to refereeing.
7. Abbreviated titles of journals cited in "*References*" MUST conform with the *World List of Scientific Periodicals* abbreviations. Papers which do not so conform may be rejected on this ground alone.
8. 25 reprints will be made available to the author free; additional reprints will be provided at cost and must be ordered on acceptance of paper.
9. Book reviews may be accepted for publication.

All communications should be addressed to Dr P.S. Lake, the Editor, Department of Zoology, Monash University, Clayton, Victoria, 3168.

AUSTRALIAN SOCIETY FOR LIMNOLOGY

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CONTENTS

|     |                                                                                                            |
|-----|------------------------------------------------------------------------------------------------------------|
| 1   | A. G. ... and J. A. ...<br>Morphometric characteristics and dynamics of some major Tasmanian water storage |
| 12  | P. L. ... and J. A. ...<br>The floating islands of Lake Tassie, Victoria                                   |
| 22  | A. J. ...<br>The biological characteristics of the ...                                                     |
| 41  | P. L. ...<br>Water quality management and the ecological status of rivers                                  |
| 51  | A. ...<br>The ... of ...                                                                                   |
| 60  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 62  | P. A. ...<br>The impact of forest loss on the ...                                                          |
| 68  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 70  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 72  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 74  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 76  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 78  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 80  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 82  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 84  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 86  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 88  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 90  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 92  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 94  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 96  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 98  | P. L. ... and J. A. ...<br>The ... of ...                                                                  |
| 100 | P. L. ... and J. A. ...<br>The ... of ...                                                                  |



## CONTENTS

| Page |                                                                                                                                                             |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3    | A. Goodman and J.A. Peterson<br>Morphometric classification and estimates of lake bottom<br>dynamics for some major Tasmanian water storages.               |
| 15   | F.L. Burns, J.F. Moresby and J.A. Peterson<br>The floating islands of Pirron Yallock, Victoria.                                                             |
| 33   | A.H. Arthington<br>The biological resources of urban creeks.                                                                                                |
| 41   | P.S. Lake<br>Water quality management and the ecological nature of rivers.                                                                                  |
| 51   | A. Glaister<br>Laboratory rearing of Australian elmids larvae<br>(Elmidae: Coleoptera).                                                                     |
| 59   | B.V. Timms and C.H.S. Watts<br>Water Beetles of salt lakes near Colac, Victoria.                                                                            |
| 65   | B.A. Richardson<br>The impact of forest road construction on the benthic<br>invertebrate and fish fauna of a coastal stream in Southern<br>New South Wales. |
| 89   | J.D. Blyth and P.D. Jackson<br>The aquatic habitat and fauna of East Gippsland, Victoria.                                                                   |

## MORPHOMETRIC CLASSIFICATION AND ESTIMATES OF LAKE BOTTOM DYNAMICS FOR SOME MAJOR TASMANIAN WATER STORAGES

by

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### Abstract

It is demonstrated that the indices developed by Hakanson (1981a) for predicting the relative significance of erosion and deposition over the bottoms of the lakes provide effective morphometric indices by which Tasmanian fresh-water impoundment can be classified. The indices also produced estimates of lake-bottom dynamics in general accord with the nature of each water body.

### Introduction

The biology, chemistry, physics and distribution of lake-bottom sediments is not easily explained or predicted without some reference to general, and if possible to specific information about lake-bottom dynamics. Modern lacustrine sedimentation patterns can be related to contemporary dynamics but monitoring this can be expensive and is usually not undertaken unless for elucidating a specific problem. For instance it might be necessary to estimate the area over which sediments with an affinity for toxic substances may be depositing.

### Hakanson's energy-topography factor

Some interest attaches to the possibility that detailed results from study of lake-bottom dynamics might be applicable elsewhere, especially if they can be related to easily-measured lake properties such as those provided by morphometric analysis.

Hakanson (1981a) has suggested that the observed percentage areal distributions of erosion and transportation ( $a_{E+T}$ ) and sediment accumulation ( $a_A = 100 - a_{E+T}$ ) in some Swedish lakes which have been mapped in detail is related to indices which can be calculated from three standard morphometric parameters : lake area ( $a$ ), mean depth ( $D$ ) and maximum depth ( $D_{\max}$ ). The three indices are :

$$1) \text{ the energy factor } E = \left| \left[ \frac{(a^{1/2})}{D_{\max}} \right] - 0.2 \right|$$



which related to the wind energy and bottom dynamics,

$$2) \text{ the slope factor } S = \log_{10} \left[ \frac{60.6 * D}{a^{1/2}} \right]$$

which shows that transportation processes dominate on slopes greater than 4.6% (see Hakanson, 1977),

$$3) \text{ the lake form factor } F = \frac{D_{\max}}{3 * D}$$

which characterizes the distinction between lakes with convex and concave hypsographic curves that have high values for  $a_{E+T}$ .

He then applies regression analysis to derive the equation

$$a_{E+T} = 52.0 * E * S * V + 19.3$$

to describe the relationship between the indices, which he named the 'energy-topography factor'.

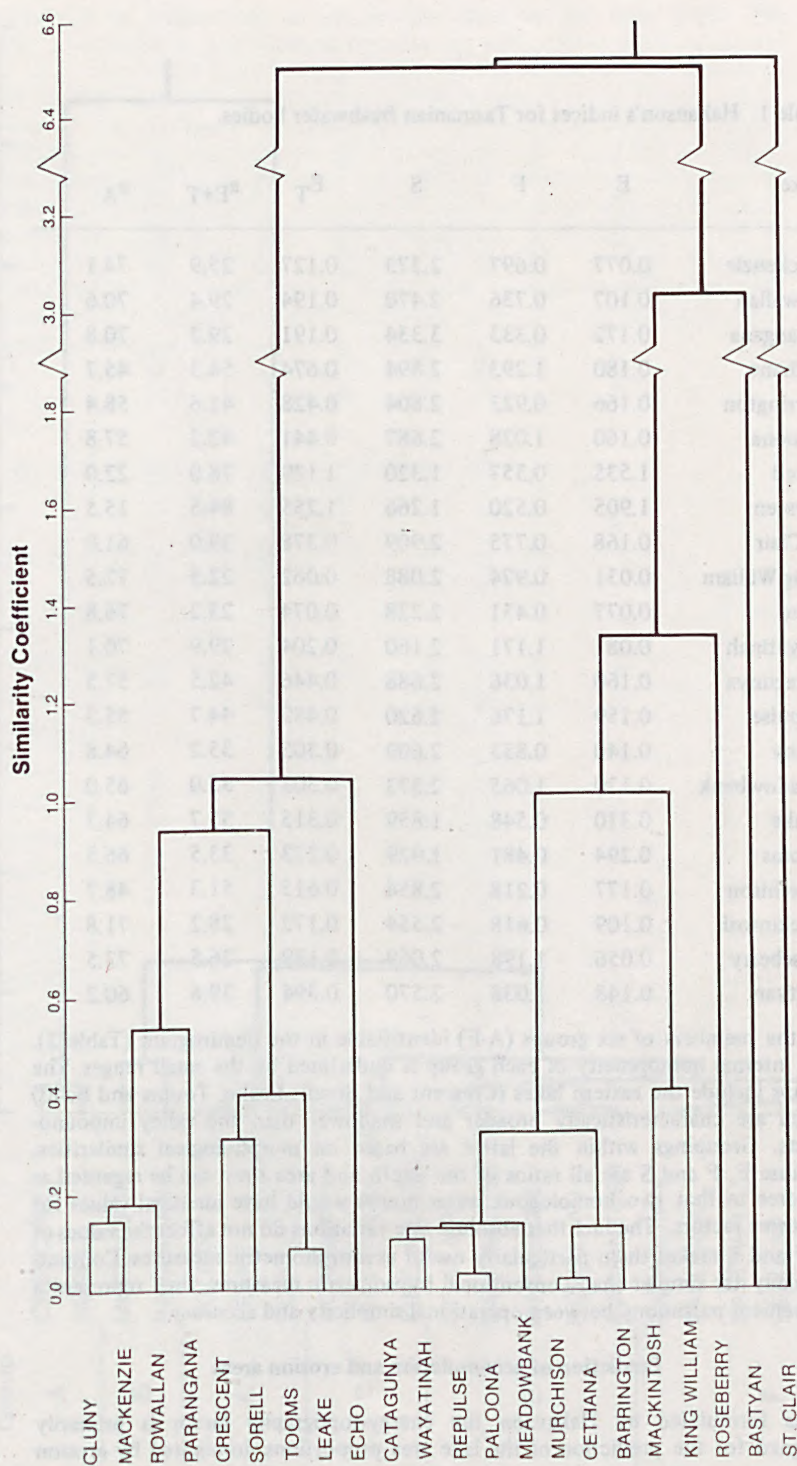
This predictive model for the proportion of the lake floor affected by erosion, transportation and accumulation in single-basin lakes — in multi-basin lakes each basin should be treated as a separate entity — has been applied to the Tasmanian water impoundments (Table 1). The morphometric parameters were derived from Peterson and Missen (1979) and the energy-topography indices were calculated using an interactive computer program (Appendix).

#### Classification of lake morphometry

Lakes, being three dimensional "solid figures", are amenable to cross-sectional plan and hypsometric analysis. The standard morphometric parameters listed in Hutchinson (1957, p.164) and augmented by additional ones listed in Hakanson (1981b) can be used to sort lakes into morphometric groups. Alternatively Hakanson's indices E, S and F could be used. These indices incorporate major morphometric parameters in a way that relates to important aspects of limnology and so it is worth testing the proposition that the indices offer an effective means of sorting lakes into meaningful groupings.

The twenty-two lakes listed in Table 1 were classified using hierarchical clustering with group averaging (Mather 1976, p.320). The results are conveniently displayed as a dendrogram (linkage diagram). The first analysis used nine morphometric parameters derived by Peterson and Missen (1979, pp.5-6): length, mean breadth, mean depth, area, volume, maximum depth, shoreline development, volume development and relative depth. Figure 1 shows the linkage order. Apart from the two sets of shallow eastern lakes (Crescent and Sorell; Leake and Tooms) the diagram is difficult to interpret and gives rise to few clear groupings due to the broad spread of similarity values.

When the values of E, S and F listed in Table 1 are used in the grouping procedure a cleaner pattern emerges (Figure 2). The linkage is clearly much more coherent with relatively homogeneous groups being formed quickly, and more disparate groups joining at relatively high levels of dissimilarity. If clarity of group definition is an important criterion, as it usually would be, the Hakanson indices perform well. The mean values and ranges of E, F and S were calculated



1. Dendrogram for Tasmanian water bodies based on nine morphometric parameters



Table 1. Hakanson's indices for Tasmanian freshwater bodies.

| Lake         | E     | F     | S     | E <sub>T</sub> | <sup>a</sup> E+T | <sup>a</sup> A |
|--------------|-------|-------|-------|----------------|------------------|----------------|
| Mackenzie    | 0.077 | 0.697 | 2.373 | 0.127          | 25.9             | 74.1           |
| Rowallan     | 0.107 | 0.736 | 2.470 | 0.194          | 29.4             | 70.6           |
| Parangana    | 0.172 | 0.333 | 3.334 | 0.191          | 29.2             | 70.8           |
| Cethana      | 0.180 | 1.293 | 2.894 | 0.674          | 54.3             | 45.7           |
| Barrington   | 0.166 | 0.923 | 2.804 | 0.428          | 41.6             | 58.4           |
| Paloona      | 0.160 | 1.028 | 2.687 | 0.441          | 42.2             | 57.8           |
| Sorell       | 1.535 | 0.557 | 1.320 | 1.129          | 78.0             | 22.0           |
| Crescent     | 1.905 | 0.520 | 1.266 | 1.255          | 84.5             | 15.5           |
| St Clair     | 0.168 | 0.775 | 2.909 | 0.378          | 39.0             | 61.0           |
| King William | 0.031 | 0.974 | 2.088 | 0.062          | 22.5             | 77.5           |
| Echo         | 0.077 | 0.431 | 2.228 | 0.074          | 23.2             | 76.8           |
| Wayatinah    | 0.081 | 1.171 | 2.160 | 0.204          | 29.9             | 70.1           |
| Catagunya    | 0.160 | 1.036 | 2.688 | 0.446          | 42.5             | 57.5           |
| Repulse      | 0.159 | 1.176 | 2.620 | 0.489          | 44.7             | 55.3           |
| Cluny        | 0.140 | 0.833 | 2.609 | 0.305          | 35.2             | 64.8           |
| Meadowbank   | 0.120 | 1.065 | 2.373 | 0.303          | 35.0             | 65.0           |
| Leake        | 0.310 | 0.548 | 1.859 | 0.315          | 35.7             | 64.3           |
| Tooms        | 0.294 | 0.481 | 1.929 | 0.273          | 33.5             | 66.5           |
| Murchison    | 0.177 | 0.218 | 2.854 | 0.615          | 51.3             | 48.7           |
| Mackintosh   | 0.109 | 0.618 | 2.554 | 0.172          | 28.2             | 71.8           |
| Roseberry    | 0.056 | 1.198 | 2.069 | 0.139          | 26.5             | 73.5           |
| Bastyan      | 0.148 | 1.038 | 2.570 | 0.394          | 39.8             | 60.2           |

for the members of six groups (A-F) identifiable in the dendrogram (Table 2). The internal homogeneity of each group is underlined by the small ranges. The groups include the eastern lakes (Crescent and Sorell; Leake, Tooms and Echo) which are characteristically broader and shallower than the valley impoundments. Groupings within the latter are based on morphological similarities. Because E, F and S are all ratios of the depth and area they can be regarded as size-free in that two homologous water bodies would have identical values for the three factors. The fact that absolute size variations do not affect the values of E, F and S makes them particularly useful as morphometric measures. Computationally far simpler than conventional hypsometric measures, they represent a convenient parsimony between operational simplicity and accuracy.

#### Prediction of accumulation and erosion areas

As formulated by Hakanson the energy-topography factor is primarily designed for the prediction of the lake area proportions dominated by erosion and transportation, or by accumulation processes. These proportions are



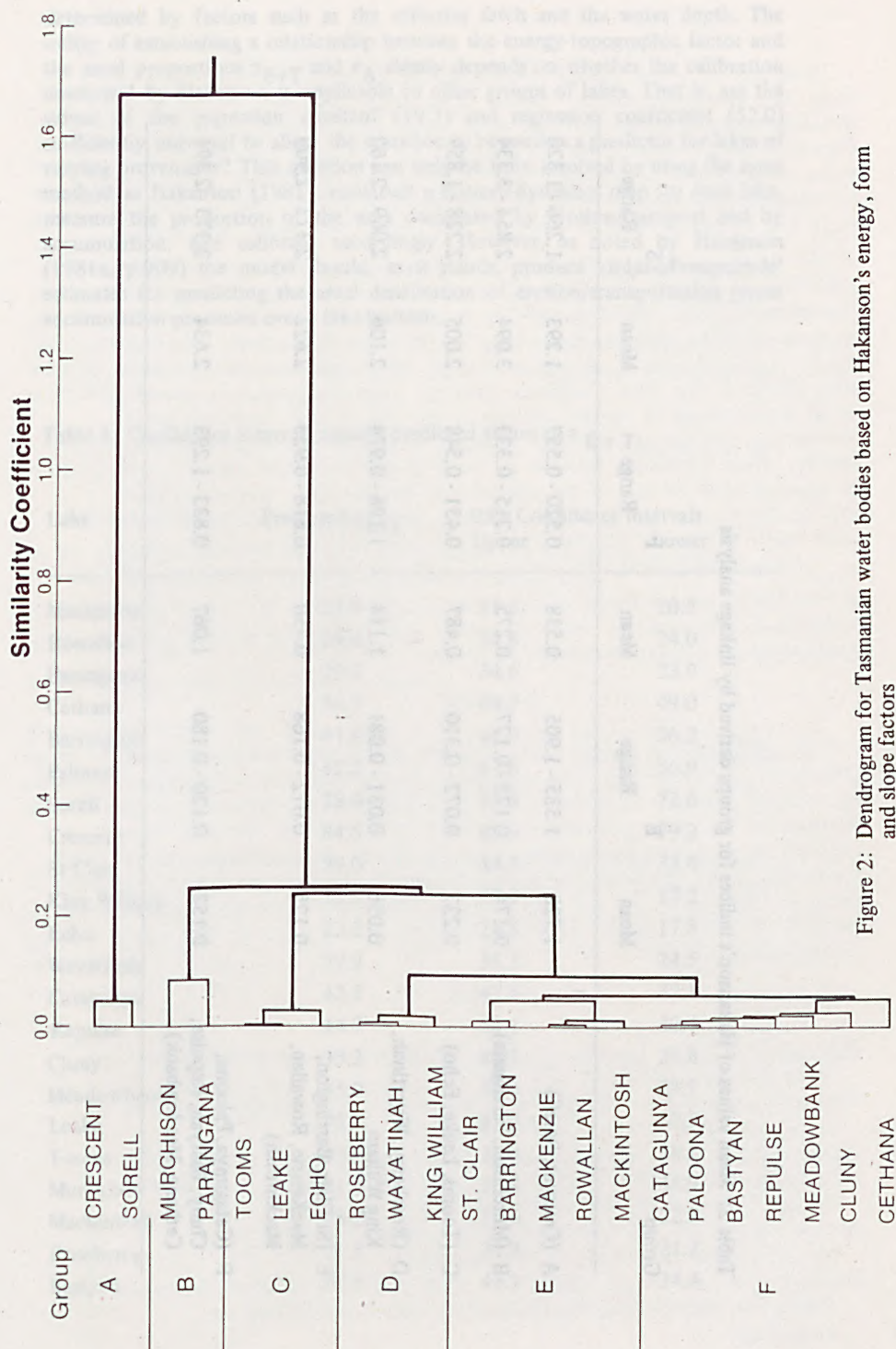


Figure 2: Dendrogram for Tasmanian water bodies based on Hakanson's energy, form and slope factors

Table 2: Mean values of Hakanson's indices for groups derived by linkage analysis

| Group                                                                       | E     |               | F     |               | S     |               |
|-----------------------------------------------------------------------------|-------|---------------|-------|---------------|-------|---------------|
|                                                                             | Mean  | Range         | Mean  | Range         | Mean  | Range         |
| A (Crescent, Sorell)                                                        | 1.720 | 1.535 - 1.905 | 0.538 | 0.520 - 0.557 | 1.293 | 1.266 - 1.320 |
| B (Murchison, Parangana)                                                    | 0.174 | 0.172 - 0.177 | 0.275 | 0.215 - 0.333 | 3.094 | 2.854 - 3.334 |
| C (Tooms, Leake, Echo)                                                      | 0.227 | 0.072 - 0.310 | 0.487 | 0.431 - 0.548 | 2.005 | 2.228 - 1.859 |
| D (Roseberry, Wayatinah,<br>King William)                                   | 0.056 | 0.031 - 0.081 | 1.114 | 1.198 - 0.974 | 2.106 | 2.069 - 2.160 |
| E (St Clair, Barrington,<br>MacKenzie, Rowallen,<br>Mackintosh)             | 0.125 | 0.072 - 0.168 | 0.750 | 0.618 - 0.923 | 2.622 | 2.373 - 2.909 |
| F (Catagunya, Palooona,<br>Cluny, Bastyan, Repulse,<br>Cethana, Meadowbank) | 0.152 | 0.120 - 0.180 | 1.067 | 0.833 - 1.293 | 2.634 | 2.373 - 2.894 |



determined by factors such as the effective fetch and the water depth. The utility of establishing a relationship between the energy-topographic factor and the areal proportions  $a_{E+T}$  and  $a_A$  clearly depends on whether the calibration developed by Hakanson is applicable to other groups of lakes. That is, are the values of the regression constant (19.3) and regression coefficient (52.0) sufficiently universal to allow the equation to be used as a predictor for lakes of varying provenance? This question can only be fully resolved by using the same method as Hakanson (1981): construct a bottom-dynamics map for each lake, measure the proportion of the area dominated by erosion/transport and by accumulation, and calibrate accordingly. However, as noted by Hakanson (1981a, p.909) the model should, as it stands, produce 'order-of-magnitude' estimates for predicting the areal distribution of erosion/transportation versus accumulation processes over a lake bottom.

Table 3. Confidence intervals around predicted values of  $a_{E+T}$

| Lake         | Predicted $a_{E+T}$ | 95% Confidence intervals |       |
|--------------|---------------------|--------------------------|-------|
|              |                     | Upper                    | Lower |
| Mackenzie    | 25.9                | 31.3                     | 20.5  |
| Rowallan     | 29.4                | 34.8                     | 24.0  |
| Parangana    | 29.2                | 34.6                     | 23.9  |
| Cethana      | 54.3                | 59.7                     | 49.0  |
| Barrington   | 41.6                | 46.9                     | 36.2  |
| Paloona      | 42.2                | 47.6                     | 36.9  |
| Sorell       | 78.0                | 83.3                     | 72.6  |
| Crescent     | 84.5                | 89.9                     | 79.2  |
| St Clair     | 39.0                | 44.3                     | 33.6  |
| King William | 22.5                | 27.9                     | 17.2  |
| Echo         | 23.2                | 28.5                     | 17.8  |
| Wayatinah    | 29.9                | 35.3                     | 24.5  |
| Catagunya    | 42.5                | 47.8                     | 37.1  |
| Repulse      | 44.7                | 50.1                     | 39.4  |
| Cluny        | 35.2                | 40.5                     | 29.8  |
| Meadowbank   | 35.0                | 40.4                     | 29.7  |
| Leake        | 35.7                | 41.0                     | 30.3  |
| Tooms        | 33.5                | 38.8                     | 28.1  |
| Murchison    | 51.3                | 56.6                     | 45.9  |
| Mackintosh   | 28.2                | 33.6                     | 22.9  |
| Roseberry    | 26.5                | 31.9                     | 21.2  |
| Bastyan      | 39.8                | 45.1                     | 34.4  |

Obviously the model can be recalibrated for use with particular groups of lakes. As a first approximation "typical" lakes for detailed study of lake-bottom dynamics might be chosen with the aid of a dendrogram developed like those in Figures 1 and 2. Alternatively the utility of the formula as it stands could be tested by non-statistical criteria. These must necessarily be based on intuitive knowledge of the morphology of the particular lakes and the kind of values of  $a_{E+T}$  and  $a_A$  which could be expected from them. Under these circumstances certain points need to be borne in mind when the probable accuracy of the predictions is assessed. The most important is the statistical reliability of the regression estimates, based on confidence levels around the original data set. Analysis of the Swedish lake data set used by Hakanson (1981, Table 10, p.908) yields a standard error of estimate of 10.64%. When applied to the Tasmanian lakes (Table 2) the 95% confidence intervals about the predictions are seen to be large enough to require caution in the use of basic predicted values, particularly towards the extreme ends of the range of energy-topography factors. These confidence intervals are based upon the assumed standard error of estimate equal to that in the original nine Swedish lakes, and it is possible that recalibration of the model with some or all of the Tasmanian lakes would yield lower confidence intervals due to the more restricted range of  $a_T$  and  $a_{E+T}$  values. Nevertheless the limited available data suggest that Hakanson's relationship between a derived energy-topography factor and the proportion of lake-bottom dominated by erosion/transport and depositional processes can, used judiciously, produce reasonable predictions.

### Conclusion

The application of energy, form and slope factors proposed by Hakanson (1981a) to a group of major water storages in Tasmania produced estimates of lake bottom dynamics in general accord with the nature of each water body. Allowing for the likely prediction errors involved, these simple measures, taken together as an energy-topographic factor, produced good estimates of the proportion of the lake bottom dominated by erosion/transport and depositional processes. Separately they are also effective summaries of the morphometric character of a water body and prove useful in classification of lakes based strictly on morphology.

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## APPENDIX The Computer Program

A short program, written in FORTRAN IV for a Burroughs 6700 computer, was developed to calculate the measures proposed by Hakanson. The program is interactive to the extent that the user enters values for the basic morphometric properties in response to statements printed by the program, and the results are printed during the running of the program.

The listing of the program is generally self-explanatory. There are no limits on the number of lakes which may be analysed; when one set of results has been processed, the user is asked whether more lakes are to be dealt with, or whether the program is to be terminated. The computer time and cost involved are low; analysis of the twenty-two Tasmanian lakes took less than 5 seconds of processing time.

Input to the program consists of the following data for each lake to be analysed:

1. the name of the lake, using up to 40 characters
2. the units in which the lake area is to be read — if the area is in hectares, a value of 01 is entered; if in square kilometres, a value of 02
3. the lake area
4. the mean depth of the lake, in metres
5. the maximum depth of the lake, in metres.

If the depth values were measured in units other than metres, a conversion factor to produce values in metres would need to be inserted. The format statements employed allow a maximum area of 99999.99 hectares or sq. kms., and maximum depth values of 999.99 metres.

Using the regression equation to calculate values of the area of the lake dominated by erosion and transport processes ( $a_{E+T}$ ), a value for the energy-topography factor greater than 1.55 will produce an  $a_{E+T}$  value of over 100%, which is meaningless. Accordingly, any value of  $a_{E+T}$  of over 100.0 is set equal to 100% (and  $a_A$  to 0%) in the program.

```
C*
C*      PROGRAM TO CALCULATE LAKE MORPHOMETRY
C*      PARAMETERS PROPOSED BY L. HAKANSON
C*      (CAN.J.EARTH SCI., VOL18,1981,899-909)
C*
C*      INPUT : 1. LAKE NAME (UP TO 40 CHARACTERS)
C*               2. WHETHER AREA IS IN HECTARES (01) OR
C*                  SQUARE KILOMETRES (02)
C*               3. LAKE AREA (IN F7.2)
C*               4. MEAN DEPTH IN METRES (IN F6.2)
C*               5. MAXIMUM DEPTH IN METRES (IN F6.2)
C*
C*      DIMENSION LNAME(40), YES(2)
```

```

DATA YES/2HYE,2HNO/
REAL MAXDEP
LKOUNT=0
PRINT 1
1 FORMAT (/10X, "ANALYSIS OF LAKE BED DYNAMICS" //)
100 PRINT 2
2 FORMAT (/5X, "WHAT IS THE NAME OF THE LAKE?")/
LKOUNT=LKOUNT+1
C*
C*      ENTER MORPHOMETRIC DATA FOR EACH LAKE
C*
READ (5,3) (LNAME(I),I=1,40)
3 FORMAT(60A1)
PRINT 4
4 FORMAT (/5X, "IF THE AREA IS IN HECTARES - ENTER 01"/
*5X "IF THE AREA IS IN SQ. KM. - ENTER 02")
READ (5,5) NTAREA
5 FORMAT (I2)
PRINT 6
6 FORMAT(5X, "ENTER A VALUE FOR THE LAKE AREA : FOR",
* "AN AREA OF 1500 HA/SQ.KM.," "5X, "ENTER 15000.00")
READ (5,7) AREA
7 FORMAT(F8.2)
C*
C*      IF LAKE AREA IS IN HECTARES, CONVERT
C*      TO SQUARE KILOMETRES
C*
IF(NTAREA.EQ.2) GO TO 8
AREA=AREA/100.0
8 CONTINUE
PRINT 9
9 FORMAT (/5X, "ENTER THE MEAN DEPTH IN M. - FOR A",
* "DEPTH OF 55M, ENTER 055.00")
READ (5,10) AVDEP
10 FORMAT(F6.2)
PRINT 11
11 FORMAT (/5X, "ENTER THE MAXIMUM DEPTH IN M. - FOR A",
* "DEPTH OF 165M, ENTER 165.00")
READ (5,10) MAXDEP
C*
C*      CALCULATE ENERGY SLOPE AND FORM FACTORS
C*
SQAREA=SQRT(AREA)
ENFAC=ABS((SQAREA/MAXDEP)-0.2)
SLOFAC=ALOG10(60.6*AVDEP/SQAREA)
FORFAC=MAXDEP/(3.0*AVDEP)
C*

```



```

C*    CALCULATE ENERGY-TOPOGRAPHY FACTOR, AND
C*    PERCENTAGE AREAS OF EROSION+TRANSPORT
C*    AND ACCUMULATION
C*
ET=ENFAC*SLOFAC*FORFAC
AET=53.0*ET+19.3
C*
C*    SET UPPER AND LOWER LIMITS FOR AREAS TO 100 AND 0
C*
IF(AET.GE.100.0) AET=100.0
AA=100.0-AET
C*
C*    PRINT OUT RESULTS FOR THIS LAKE
C*
PRINT 13, (LNAME(I), I=1,40)
13 FORMAT (/10X,"RESULTS FOR",40A1)
PRINT 14,AREA
14 FORMAT(15X, "AREA =", F8.2, "SQ.KMS.")
PRINT 15,AVDEP
15 FORMAT(15X, "MEAN DEPTH =", "F.8.2,"METERS")
PRINT 16,MAXDEP
16 FORMAT(15X,"MAX.DEPTH =" "F.8.2, "METERS")
PRINT 17, ENFAC
17 FORMAT(20X,"ENERGY FACTOR =",F10.3)
PRINT 18,FORFAC
18 FORMAT(20X,"FORM FACTOR = ",F10.3)
PRINT 19,SLOFAC
19 FORMAT(20X,"SLOPE FACTOR = ",F10.3)
PRINT 20,ET
20 FORMAT(20X,"ENERGY TOPOGRAPHY FACTOR = ",F10.3/)
PRINT 21,AET
21 FORMAT(10X,"EROSION/TRANSPORT AREA (AET) = ",F11.4,"%")
PRINT 22,AA
22 FORMAT(10X,"ACCUMULATION AREA (AA) = ", F11.4, "%")
PRINT 23
C*
C*    CHECK IF THERE ARE MORE LAKES TO BE ANALYSED
C*
23 FORMAT(20X,"IS THERE ANOTHER LAKE TO BE ANALYSED?"/
*20X, "TYPE YES OR NO"/)
READ (5,24) YNEA
24 FORMAT (A2)
IF(YNEA.EQ.YES(1)) GO TO 10
IF(LKOUNT.GT.1) PRINT 25,LKOUNT
IF(LKOUNT.EQ.1) PRINT 26,LKOUNT
25 FORMAT(/20X,13, "LAKES HAVE BEEN ANALYSED"/)
26 FORMAT(/20X,13, "LAKE HAS BEEN ANALYSED"/)
STOP
END

```





## THE FLOATING ISLANDS OF PIRRON YALLOCK, VICTORIA

by

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### Abstract

The floating islands were probably formed in 1952 when the local water table rose above the level of peaty soil formed in an enclosed depression in the volcanic plains (Stony Rises) at Pirron Yallock near Lake Corangamite, Victoria. Local and national media coverage gave prominence to many stories about the origin of the islands and how, when and why they migrated from one part of the lake to another. The relative merits of these various claims are considered.

Migration of the islands around the lake is best explained by analogy with the movement of lake ice during the early summer when the partial open-water season allows rafts of ice to gather momentum after being subjected to strong and persistent winds from the one direction.

### Introduction

Floating islands have attracted attention because they are uncommon and their behaviour (eg. Figure 1) has provided not only explanations for events in myth and legend (eg. Graves 1960, p.56) but also great scope for discussion and speculation amongst scientific and other observers. Australian examples of various kinds of floating islands have been documented from Tasmania (Tyler 1976 (a) and (b), Macquarie Island (Figures 2 and 3) (Gardner 1977) Queensland (Figure 4) and the Northern Territory (Miller et al. 1981). Accounts further afield include those from the middle Amazon (Junk, 1970) Estonia (Hutchinson 1957, pp. 75 - 75) and Chile, Laguna de Tagua Tagua, (Heusser 1981). The existence of floating islands in prehistoric times has been invoked to explain certain features evident from detailed documentation of peat stratigraphies in Denmark (Jorgenson 1963). In Peru the Urcos people live in floating reed-island homes (see Figure 5) on Lake Titicaca (Findlay and Sheppard 1982, p. 201). Following the impoundment of the Zambezi River in Rhodesia in 1958 by the Kariba Dam, extensive mats of floating water-fern (*Salvinia auriculata*) quickly developed, and by 1960 occupied approximately 10% of the Lake area (Boughey 1963). These mats were colonised by a great variety of vascular plants, including banana plants and tree seedlings from the riparian forests of the area, but no tree seedlings were observed to survive more than a few months on the mats. Permanent colonies of semi-aquatic plants such as *Phragmites mauritianus*

and open ground ruderals such as *Althernanthera nodiflora*, however, were established. The action of wind on these colonised weed mats were observed to produce results similar to those of a wind-blown ice-pack, snapping off the trunks of half-submerged trees, and generating varying patterns of movement depending on the strength and direction of the wind, and the size and composition of the mat both above and below water. Mitchell (1979) and Mitchell, Petr and Viner (1980) have described similar water fern mats from New Guinea (eg. from the middle Sepik River) and refer to many other accounts of the nature and problems associated with such floating mats.

The floating islands of Pirron Yallock (see Figure 6) are of particular value, because they are comparatively accessible and, unlike some (eg. the now drowned features in the Lagoon of Islands, see Tyler 1980) are protected by their status as a Fisheries and Wildlife Reserve (The Floating Islands Lagoon Nature Reserve, Victoria — see Anon. 1981a). Much public interest is aroused from time to time with press coverage at local (Anon. 1976) State (eg. Hitchings 1976, Roberts 1980), and national (Anon. 1981b) levels.

Nature-lovers have also derived much pleasure from contemplating the islands and their lagoon at Pirron Yallock, and many tourists have purchased the booklet published by the Environment Studies Association of Victoria (Morris and Withell 1981) at the Koala Motel opposite the vantage point overlooking the Floating Islands Lagoon Reserve on the Princes Highway 17.6 km west of Colac, Victoria.

The present study was undertaken in recognition of the need for a more detailed limnological study than has so far been generally available to either tourists or scientists.

Some interest attaches to the identification of the type of floating island found at Pirron Yallock. The Queensland example mentioned above is at Bromfield Swamp where a floating mat, dominated by *Cyperus platystylis*, is found (Kershaw 1975, p. 176). At Lagoon of Islands woody plants have taken root at scattered locations where reed swamp debris colonised by sedge had accumulated sufficiently to allow seedlings to develop. The islands there followed a growth and decay cycle whereby the weight of the terrestrial plants depressing the reed mat and waterlogging of roots brings about its demise. The man-modified reed mats of lake Titicaca exemplify another type of floating island, and yet another is typified by those of Macquarie Island which are composed of peat, up to 2m thick. These are thought to form with colonisation by terrestrial plants at lake edges on a base initially provided by anchored water plants (mainly *Myriophyllum*) and algae, the vegetation association changing as the peat cover thickens so changing the depth to watertable (Gardner 1977).

Some of the floating islands found in water impoundments while full supply levels are being established represent another type. Here, the raised water levels offer the opportunity for particular portions of any peaty soils on the valley side to float away instead of being drowned or broken up by waves. One of us (FLB) has observed such minor features (Figure 7) during the filling (1969-70) of Lake Tarago (Victoria). These small features congregated in lee-side (east) bays and from time to time were redistributed after being subject to strong winds, their mobilization perhaps being aided by changes in water level. The particular floating tussock mat pictured (Figure 7) was photographed by F.L.B. after he had observed it making south toward the Tarago dam, (Jan. 1975).

The examples at Pirron Yallock are different from all of these floating island types.





Figure 1: Short-time-lapse of photographs taken April 1980 proving mobility for the floating islands of Pirron Yallock. Views are from the turning-circle at the end of access track from highway. Courtesy, Ministry of Conservation.



Figure 2: Floating Tussock Island of Brother's Lake, Macquarie Island Jan. 1980. Reproduced with kind permission, Director, Antarctic Division, Dept. of Science and Technology, Antarctic Division. Photography by G.W. Johnstone.



Figure 3: Lake with floating island near Mt. Elder, Macquarie Island Feb. 1976. Reproduced with kind permission, Director, Antarctic Division, Dpet. of Science and Technology, Antarctic Division. Photography by G.W. Johnstone.



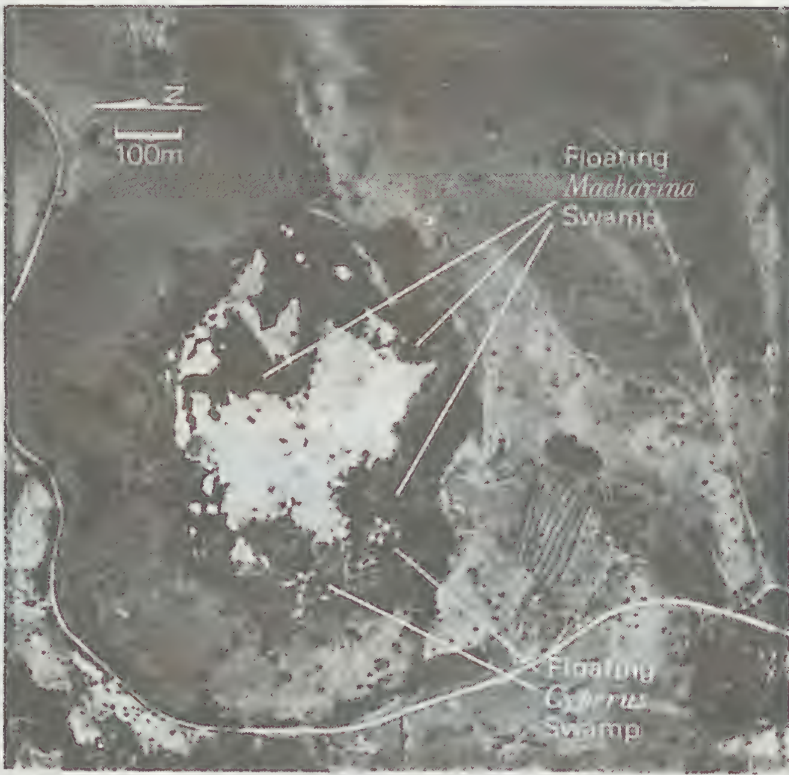


Figure 4: Bromfield Swamp, North East Queensland (after Kershaw 1973, Figure 2).



Figure 5: Floating Reed Island of Urcos Indians, Lake Titicaca, Peru (Photo JFM)

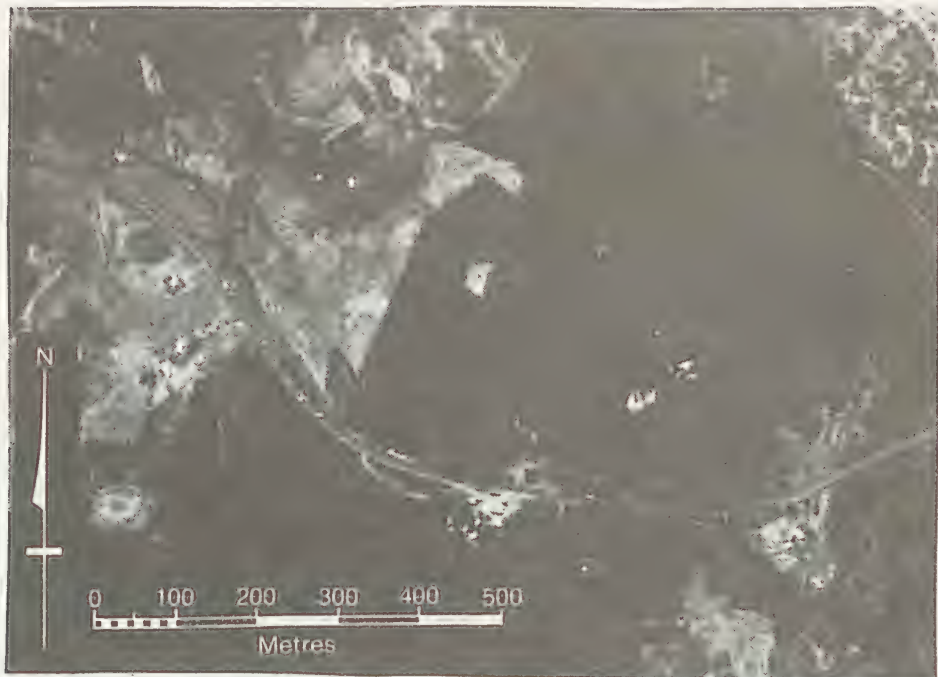


Figure 6: Enlargement from vertical air photograph (3492-26 Corangamite 7521 M/s Run 5) showing Pirron Yallock stony rises. South-western extremity of Lake Corangamite appears in top right hand corner. Boundary between stony rises and older basalt flow is marked by the contrast between the uncleared stony country (dark) and the pasture with good soil cover (light) – bottom right. The flooded depression (centre) with floating islands is here shown for 8/4/80 when the mobile floating islands were in the eastern neck. Photo reproduced by kind permission Director, Crown Lands and Survey, Melbourne.



Figure 7: Ephemeral floating tussock island aground, east end of the Tarago water impoundment (Vic.) having been made buoyant by rising water levels several years before, during the initial filling of the reservoir (1969-70).





## The Origin of the lagoon and floating islands of Pirron Yallock

### Geomorphology

The Floating Islands Lagoon occupies an enclosed depression typical of those found in the Stony Rises. These features are well documented (eg. Skeats and James 1937, Hills 1951, p. 189, Ollier and Joyce 1964) and are characteristic of many young lava flows that have not been exposed to weathering long enough to develop a continuous soil cover. The aerial photograph (Figure 6) shows the boundary between the stony rises and an older, soil-covered basalt flow to the south. The younger lava supporting the stony rises, has displaced a rivulet, forcing it to the edge of the lava flow. The drainage pattern on the stony rises is immature and disorganised due to the chaotic topography. The maze of rises and depressions originates from differential internal drainage of lava leaving sections of the cooling crust unsupported so that they collapse in such a way that enclosed depressions may form (see Ollier 1967 and Williams and McBurney 1979 pp. 99-100). Some flows in the area, but closer to Mt. Porndon than the Floating Islands lagoon, support lava caves rather than depressions because the crust has maintained its integrity despite some drainage of lava from beneath, but only the most minor of cave-like features have been reported in the Pirron-Yallock-Pomborneit Stony Rises. It has been postulated that the lava that drained from beneath the flow surface of the stony rises is represented in the many distinct and minor tongues of lava that protrude at the edge of the flow to give sections of the shore of nearby Lake Corangamite a very irregular outline (Ollier 1969, p. 60).

### Age and origin of the islands

A sequence of events leading to the present condition and behaviour of the floating islands may be envisaged. First, the necessary peat formation must date from a time before the depression was flooded. The interface and density difference between the peat and the comparatively unweathered lava flow would have been sharp and apparently the buoyancy of the peat and its vegetative cover upon flooding was enough to break any roots that may have bound the peat to the basalt blocks beneath.

The drainage changes accompanying these events are hard to document but Shepherd (1983 pp. 10-11), quoting recollections of long-time local residents suggests that the depression now containing the floating islands was swampy until 1952 when the swamp was flooded. As the water level rose the peat mat began to float, and break up, so that some sections floated and others sank.

The change from swampy to lacustrine conditions took place during the wettest year on record (eg. see Bayly and Williams, 1966, Figure 14) for the nearby meteorological station of Camperdown where the 1898-1974 mean is 777.5mm. The 1952 total was 1253.4mm for a station with rainfall distributed normally about the mean with a standard deviation of 137.7mm (Churchill et al. 1978 Figure 3.5.2).

Reasons for the change in the water-holding status of the depression around 1952 are not known, but several suggestions can be made. First there is the possibility that successive up-grading of the causeway through the depression (now part of the Princes Highway) has favoured the change from swamp to lagoon. A track was laid through the swamp last century, pavement work was carried out in 1929/30 and the highway re-aligned in 1963 (*pers. comm.* F.G.

Lodge, Divisional Engineer, C.R.B., 10 August 1981 reference F. McD/NR Warrnambool Office). Thus water has not been able to flow easily between the floating island depression and its former southern arm (now cut-off by the causeway) for many decades and not at all since 1963.

Settlement of the area dates back well over a century. Spreadborough and Anderson (1983 pages 129 and 137) record that the area surrounding the lagoon was taken up for sheep stations in 1849 ("Parring Yallock" and "Stony Rises"). Stone walls, characteristic of this part of the Western District, date from a period several decades later when better land management was called for in the face of difficulties (rabbit plague, dingoes, disease etc.). Well-built stone walls are found near the lagoon together with the remains of a drainage channel across the lowest point of the basin at the northernmost part of its perimeter (G. Cerini, District Superintendent, Fisheries and Wildlife Division, Warrnambool, pers. comm.). It is probable that the establishment of the channel allowed the drainage of the depression, and the development of a peat mat. Subsequent collapse and in-filling of the channel may have restored the former capacity of the depression to hold water and allowed floatation of the peat mat.

Water level records for Western District lakes that have not been artificially drained show a steady decline since early settlement by Europeans (eg. Currey 1970). Churchill *et al.* (1978) have attributed to this increased evaporation following a rise in mean temperatures since 1870. It is probable therefore that the swampy conditions that led to the formation of the peat mat were encouraged by both artificial drainage and climatic-change.

### Limnological Aspects

#### Morphology

Four echo-sounding traverses were made of the lake using a Koden echosounder. These indicated that the bottom of the lake is substantially flat with a water depth of 2.5m to 3.0m at the time of inspection (18 April 1981). The flat bottom is surrounded by steeply-sloping edges. Thus the islands are free to move around the lake unless there is insufficient water to float them, (see Table1).

A study of the Lands Department aerial photographs of 23 November 1969 and 8 April 1980, and a number of ground-level photographs taken over the years, suggests that not all the islands in the lake are floating. In fact during the 1982/83 summer, with the water level drawn down to A.H.D. 135.33m compared to A.H.D. 136.13m in April 1981, none of the islands appeared to be free-floating. However, with normal water levels it appears that there are four floating islands on the lake, and these have been designated as islands a, b, c and d on the sketch plan of the lake (see Fig. 8). The size and shape of these islands has been deduced from the aerial photographs, and is approximate only, but the relative sizes and vegetation cover are as observed on April 18, 1981.

It appears that these islands move around a roughly rectangular basin with dimensions 200m in the NE-SW direction, and 100m in the NW-SE direction. The high timber-covered banks on the NW and NE sides of this basin would give more protection from wind than the lower and comparatively more open SE and SW sides. Therefore, if wind is the main influence on the movement of the



floating islands, they would be expected to move mainly between the NW and NE sides of the basin. A study of the available photographs shows that this is the case, and in fact they have been clustered on the NW side as shown on the sketch plan (Fig. 8) for at least the past two years.

#### Temperature and dissolved oxygen

A temperature and dissolved-oxygen profile was measured in the deepest part of the lake on the morning of 18 May 1981, using a Yellow Springs Model 54 ABP dissolved oxygen meter with a Model 5739 probe (Table 2). These measurements indicate that the lake was substantially isothermal and mixing to the bottom without any significant thermal stratification. The low dissolved oxygen in the bottom 0.2m would be due to the probe entering the region of rotting vegetation and mud on the lake bed where the biological oxygen demand would be high.

**TABLE 1: Variation in water level, Floating Islands, Pirron Yallock**

(The lake was used for filling fire-fighting tankers during the severe Western District fires in February 1983. This, together with the 1982/83 drought and the withdrawal of water to supply a nearby motel has resulted in lower than normal water levels during September to November 1983, despite the very good spring rainfall).

|  | Date         | Water level<br>(A.H.D.) | Rise(+), Fall(-)<br>(m) |
|--|--------------|-------------------------|-------------------------|
|  | May 1961     | 136.48                  |                         |
|  | 19/5 (1981)  | 136.13                  | 0                       |
|  | 30/5         | 136.18                  | +0.05                   |
|  | 13/6         | 136.21                  | +0.08                   |
|  | 30/6         | 136.26                  | +0.13                   |
|  | 16/7         | 136.33                  | +0.20                   |
|  | 1/8          | 136.40                  | +0.27                   |
|  | 29/8         | 136.55                  | +0.42                   |
|  | 3/10         | 136.60 (peak)           | +0.47                   |
|  | 11/11        | 136.54                  | +0.41                   |
|  | 8/12         | 136.43                  | +0.30                   |
|  | 1/1 (1982)   | 136.34                  | +0.21                   |
|  | 11/1         | 136.31                  | +0.18                   |
|  | 7/2          | 136.13                  | 0                       |
|  | 16/2         | 136.10                  | -0.03                   |
|  | 17/3         | 135.95                  | -0.18                   |
|  | 26/3         | 135.95                  | -0.18                   |
|  | 25/5         | 135.94                  | -0.19                   |
|  | 22/9 (1983)  | 136.10                  | -0.03                   |
|  | 13/10        | 136.09                  | -0.04                   |
|  | 10/11        | 136.11                  | -0.02                   |
|  | 27/12 (1984) | 135.87                  | -0.26                   |

(data supplied by Road Construction Authority)  
datum for present survey

TABLE 2: Temperature and dissolved oxygen profile, 18 May 1981; Floating Islands Lake, Pirron Yallock

|        | Depth<br>m | Temp.<br>°C | Dissolved Oxygen<br>mg/l | Oxygen<br>% Sat. |
|--------|------------|-------------|--------------------------|------------------|
|        | 0.0        | 11.6        | 6.5                      | 59               |
|        | 0.5        | 11.6        | 6.1                      | 55               |
|        | 1.0        | 11.5        | 5.9                      | 53               |
|        | 1.2        | 11.3        | 5.8                      | 52               |
|        | 1.5        | 11.3        | 5.5                      | 50               |
|        | 2.0        | 11.2        | 5.3                      | 48               |
|        | 2.5        | 11.1        | 5.2                      | 47               |
|        | 2.7        | 11.1        | 1.3                      | 10               |
| Bottom | 2.9        | 11.1        | 0.0                      | 0                |

Soil samples were taken from three to four islands at depths of 200 and 500mm, stored immediately in polythene bags and analysed within two weeks. The most westerly island (at the time of sampling, "a") was 300mm thick so only a 200mm depth sample was taken.

Soil water was filtered off before analysis and included with soil moisture measured by loss on drying. Soil water was analysed, the soil dried and ignited at 650° and a composite ash sample analysed for metals.

The peaty soil consisted of roots, stems and leaves, decomposed humus and brown ooze.

Results given in Table 4 show that the soil was 91-95% carbon (volatile on dry basis), and retained from 8 to 46% water which was, as could be expected, higher for samples taken at the "water table" of each island. The high proportion of volatile carbon in the soil (av. 92.9% on dry basis) confirms that it is basically a peat mat.

In all cases, as the results in Tables 3 and 4 show, the associated soil moisture salts were on the average 2.7 times more concentrated than the lagoon water on the sampling day. There was a larger average concentration of iron and potassium (16.2 and 2.0 times respectively). On the other hand, average amounts of calcium and magnesium were lower: each a little more than half the corresponding values for water samples.

Ash from ignited soil samples was combined and analysed for Ca, Mg, Fe, Na and K. Silica was determined separately by weight loss after fuming with HF. Approximately half of the ignited ash is silica, and the remainder is divided about equally between Ca, Mg, Fe and Na.

Soil pH averaged 5.0, which might be expected in peat high in humus.

TABLE 3: Water Analysis

| Location              | Depth<br>m | Ca <sup>2+</sup><br>(mg/l) | Mg <sup>2+</sup><br>(mg/l) | Fe <sup>3+</sup><br>(mg/l) | Na <sup>+</sup><br>(mg/l) | K <sup>+</sup><br>(mg/l) | Cl <sup>-</sup><br>(mg/l) | pH @<br>20° | TDS<br>mg/l |
|-----------------------|------------|----------------------------|----------------------------|----------------------------|---------------------------|--------------------------|---------------------------|-------------|-------------|
| At temp. profile site | 1.5        | 18.2                       | 36.5                       | 0.29                       | 112                       | 8.54                     | 210                       | 7.6         | -           |
| At temp. profile site | 2.9        | 18.2                       | 34.6                       | 0.05                       | 110                       | 3.26                     | 204                       | 7.2         | -           |
| Near "c" Island       | 1.2        | 19.4                       | 36.4                       | 0.18                       | 111                       | 3.21                     | 206                       | 7.5         | 490         |
|                       | 2.4        | 17.1                       | 34.7                       | 0.23                       | 111                       | 5.46                     | 219                       | 7.3         | 489         |
| West End              | 1.2        | 18.5                       | 36.2                       | 0.19                       | 111                       | 2.94                     | 206                       | 7.4         | 495         |
|                       | 2.4        | 18.8                       | 36.5                       | 0.19                       | 111                       | 2.96                     | 212                       | 7.5         | 478         |
| Mid Lake              |            | 18.4                       | 36.3                       | 0.19                       | 110                       | 3.21                     | 204                       | 7.3         | 488         |
| Av.                   |            | 18.4                       | 36.0                       | 0.20                       | 111                       | 3.56                     |                           |             |             |

Table 3: Water analysis, Floating Islands Lake, Pirron Yallock



TABLE 4: Soil and soil water analysis

| Location            | Depth<br>(m) | Soil<br>moisture<br>(free %) | Ash (650°)<br>(on dry<br>soil %) | Volatile C<br>(by diff. %) | Soil water (mg/l) |      |      |     | Cl <sup>-</sup> | K <sup>+</sup> | Na <sup>+</sup> | pH @<br>20° | TDS<br>mg/l |
|---------------------|--------------|------------------------------|----------------------------------|----------------------------|-------------------|------|------|-----|-----------------|----------------|-----------------|-------------|-------------|
| Island "d"          | 0.2          | 16.7                         | 6.65                             | 93.4                       | 19.1              | 41.4 | 8.6  | 224 | 24.3            | 390            |                 | 5.0         | 718         |
|                     | 0.5          | 26.8                         | 4.92                             | 95.1                       | 9.78              | 23.8 | 4.6  | 191 | 9.64            | 346            |                 | 4.2         | 664         |
| Island "c"          | 0.2          | 8.0                          | 8.75                             | 91.3                       | 31.6              | 50.0 | 18.8 | 204 | 46.0            | 780            |                 | 4.6         | 1435        |
|                     | 0.5          | 16.2                         | 6.55                             | 93.5                       | 38.8              | 12.7 | 11.3 | 958 | 38.0            | 1737           |                 | 4.2         | 3196        |
| Islands "b" and "c" | 0-0.2        | 46.4                         | 8.93                             | 91.1                       | 30.9              | 60.8 | 0.4  | 187 | 30.1            | 319            |                 | 7.1         | 587         |
| Average             |              | 22.8                         | 7.16                             | 92.9                       | 26.0              | 60.6 | 8.7  | 353 | 29.6            | 714            |                 | 5.0         | 1320        |
| Av. ash analysis %  |              |                              |                                  |                            | 5.7               | 6.0  | 5.3  | 6.0 | 0.8             |                |                 |             |             |

## Movement of Floating Islands

By analogy with the movement of lake-ice during the partial open-water season in the Arctic, when rafts of ice gather momentum after being subjected to persistent winds from one direction (Peterson 1965) it may be assumed that wind is the main motivating force on the floating islands, and bottom friction and water drag are the main resisting forces. Accordingly an analysis of the expected movement of islands taking into account variation in size and in vegetation height has been made (Appendix A) and is shown in graphical form (Figure 9). The interesting points which come out of this analysis are:—

- The low wind velocity required to get the islands moving if they are floating free of the bottom (2.5 to 6.5 m/s or 5 to 13 mph)
- A lower wind velocity is required to get the smaller islands, or islands with high vegetation, moving
- The larger islands, irrespective of vegetation height, will move off at higher speed and momentum than the smaller ones and will therefore take more stopping.

It can therefore be appreciated how different patterns of island location could develop and give rise to claims that the weather could be forecast from these patterns. A light wind would send the smaller islands scurrying off across the basin, but, if the wind continued to rise, the larger islands would take off, quickly catch up and shoulder them aside. If the wind suddenly stopped or changed the islands could even bounce off the far shore or each other and finish up on the less frequented SW or SE side of the basin. Such wind changes are characteristic of Victorian climates, and it appears that any serious attempt to correlate the positions of the floating islands with weather patterns, should also take into account the wind behaviour and its influence in positioning the islands. The limited lagoon size indicates that observation of movement will be possible for only short periods of time for any one weather pattern.

The future of the floating islands.

The islands are the centre-piece of a nature reserve administered by the Fisheries and Wildlife Division, from the regional offices in Warrnambool, Victoria.

A management plan has been compiled (Shepherd 1983) and there should be little trouble in following it in general terms. However, just as the lagoon basin was once drained to provide water for a small farm to the north, there is still the problem of controlling water use. Table 1 shows that water levels have not risen substantially since the breaking of the 1982/83 drought and it is possible that the islands may become "grounded". A significant component of the interest generated by these features involves their movement and so management policy will no doubt include provision for guarding against the islands "taking root".

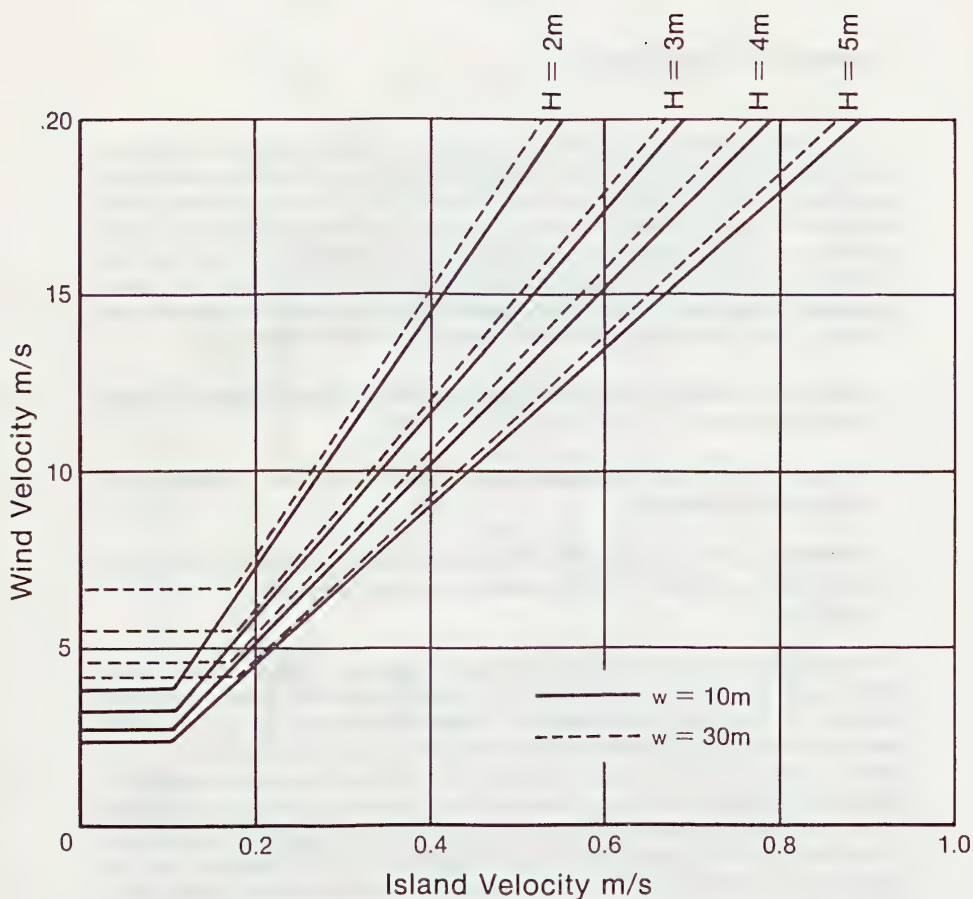


Figure 9: Estimated relationship between wind and island velocities for islands of varying dimensions (See also Appendix A)

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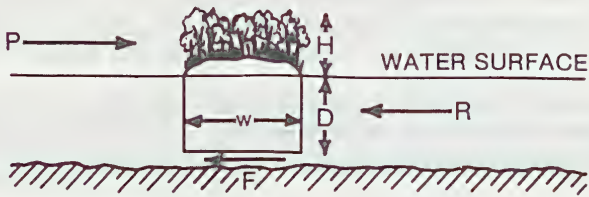
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## Appendix A.

### Movement of Islands



H = Height of Island and Vegetation (2 to 5m)

D = Depth of Island — 2.5m assumed

w = Width of Island in direction of travel (10 to 30m)

L = Length of Island transverse to direction of travel (m)

### Forces Acting

Wind —  $P = 0.05 V_w^2 LH$  Kg

Water Resistance  $R = 50 V_i^2 LD$  Kg

Bottom Friction  $F = 0.15wL$  Kg

$V_w$  = Velocity of Wind (m/s)

$V_i$  = Velocity of Island (m/s)

Bottom friction coefficient has been estimated from reported observation of island travelling 18m in 5 minutes and from photograph of this island estimating  $H = 3\text{m}$  and  $w = 4\text{m}$ .

Island Velocity  $V_i$  for  $w = 10$  and  $D = 2.5$

| Wind Vel.<br>$V_w$ | H = 2m                                                            | H = 3m                                          | H = 4m                                          | H = 5m                                          |
|--------------------|-------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|                    | $V_i = \sqrt{\frac{0.10V_w^2 - 1.5}{125}}$                        | $V_i = \sqrt{\frac{0.15V_w^2 - 1.5}{125}}$      | $V_i = \sqrt{\frac{0.20V_w^2 - 1.5}{125}}$      | $V_i = \sqrt{\frac{0.25V_w^2 - 1.5}{125}}$      |
| 20 m/s             | $V_i = 0.55\text{m/s}$<br>$V_i = 0$ when<br>$V_w = 3.9\text{m/s}$ | 0.69<br>$V_i = 0$ when<br>$V_w = 3.2\text{m/s}$ | 0.79<br>$V_i = 0$ when<br>$V_w = 2.7\text{m/s}$ | 0.89<br>$V_i = 0$ when<br>$V_w = 2.4\text{m/s}$ |

Island Velocity  $V_i$  for  $w = 30$  and  $D = 2.5$

|        | $V_i = \sqrt{\frac{0.10V_w^2 - 4.5}{125}}$                        | $V_i = \sqrt{\frac{0.15V_w^2 - 4.5}{125}}$      | $V_i = \sqrt{\frac{0.20V_w^2 - 4.5}{125}}$      | $V_i = \sqrt{\frac{0.25V_w^2 - 4.5}{125}}$      |
|--------|-------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 20 m/s | $V_i = 0.53\text{m/s}$<br>$V_i = 0$ when<br>$V_w = 6.7\text{m/s}$ | 0.67<br>$V_i = 0$ when<br>$V_w = 5.5\text{m/s}$ | 0.78<br>$V_i = 0$ when<br>$V_w = 4.7\text{m/s}$ | 0.87<br>$V_i = 0$ when<br>$V_w = 4.2\text{m/s}$ |

## THE BIOLOGICAL RESOURCES OF URBAN CREEKS<sup>1</sup>

by

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### Abstract

Most Australian cities have developed along large rivers that are fed by a network of small creeks draining through urban and suburban areas. The plant and animal communities associated with urban creeks offer a variety of resources which can enrich human life. The diversity of plant communities, their associated terrestrial fauna, and the diversity of aquatic invertebrates and fish in the Brisbane region are described and the scientific, educational and recreational values of these resources are discussed. Some of the effects on the creek communities of the creek hydrology, urban development, water pollution and the establishment of introduced plants and fish are described for Brisbane. An example of the management problems arising from competing uses of urban creeks highlights the kind of difficulty facing management authorities. However, multiple uses of urban creeks need not be incompatible. Management strategies are needed to evaluate aquatic resources and to set management constraints and priorities at the level of Local and State governments.

### Introduction

Most Australian cities have developed along large rivers that are fed by networks of small creeks draining through urban and suburban areas. Urban development has resulted in substantial changes to the character of creeks and their immediate environs, their water quality and their aquatic life. These changes have been well documented in the Brisbane region, which provides an example of the biological resources of urban creeks and a case history of the effects of man on these resources.

### Flora and Fauna of Brisbane's Urban Creeks

Several types of vegetation are commonly found along creeks in the Brisbane region — rainforest (low closed forest with sparse ground cover), wet and dry sclerophyll forest dominated by *Angophora*, *Casuarina*, *Eucalyptus*, *Acacia*, *Banksia* and *Leptospermum*, with grasses, shrubs and grass tree (*Xanthorrhoea*) forming understory and ground cover, and paper bark (*Melaleuca*) stands in swampy areas along drainage channels. About 25 Marsupial and Monotreme species have been recorded in association with these types of vegetation (Cunningham 1978). Thus it is possible to see platypus, marsupial mice and rats, bandicoots, potaroo, pademelons, possums, koala and gliders amongst

<sup>1</sup> Originally presented as a Keynote Address to the 1983 Annual Conference of the Australian Society for Limnology.

riparian vegetation. During the recent Brisbane Wildlife Survey several marsupial species were recorded only in the vicinity of urban creeks, particularly in the upper parts of their catchments where steep gradients have prevented intense urban development. For example, the fawn-footed melomys, the yellow-footed antechinus and the planigale were recorded only in rainforest remnants along Moggill Creek in the Upper Brookfield area. Platypus can be seen where Gold Creek joins Moggill Creek and in parts of the Kenmore area where tree cover has been restored along the banks of Moggill Creek (Davies 1983., Fig. 1).

The reptiles associated with Bulimba Creek have been observed for a 10-year period. During this time, 10 species of snakes, 7 species of skinks and ghecos, the eastern water dragon, the sand goanna, Burton's legless lizard and two tortoises have been sighted (Milton, pers comm. 1983). There are 32 species of frogs in the Brisbane region; at least 8 of these are commonly seen along urban creeks, together with the introduced cane toad (Ingram 1983).

More precise data are available on the fish and invertebrate fauna of Brisbane's creeks. A survey of 55 creeks around Brisbane between the Logan River to the south and Brupengary Creek to the north, and west to Ipswich, has yielded 17 native fish species and 6 introduced species (Table 1; Arthington *et al.* 1983). The native species are common also in the Brisbane River and the associated systems of the Bremer and Stanley Rivers (Williams 1971). The richest associations of species occur in the upper reaches of the North Pine River, Kobbie Creek, Enoggera Creek, Ithaca Creek and Moggill Creek (Fig. 1). At these sites there are 8-14 native species, including rainbow fish, smelt, gudgeons, hardyheads, olive perchlet, mouth almighty, catfish and eels.

The invertebrate fauna of a 10 km section of Bulimba Creek has been studied for a 15 month period during which a variety of sampling and collection methods was used to determine the diversity of the fauna. These methods included scoop samples from creek substrates, drift sampling, and dip-netting in the creek amongst vegetation and debris (Arthington *et al.* 1982). The fauna collected by these methods included Cnidaria (one species), Platyhelminthes (probably 5 species), Nematoda (6 species), Mollusca (12 species), Annelida (9 species), Hydracarina (2 species), Crustacea (14 species), and 200 species of insects.

These studies and observations around Brisbane indicate the potential richness of animal life associated with creeks despite the fact that most are somewhat modified by urban development. What is the value of these biological resources of the community?

I see three major attributes of creek ecosystems worthy of consideration — their scientific value, their educational value and their contribution to recreation in the urban environment.

### Scientific Value

The biota of any ecosystem represents a bank of genetic material available for future scientific study and possibly for future use. Stream ecosystems are highly accessible and easily manipulated and so are suitable for the study of ideas and theories in the forefront of ecological debate eg. the stochastic or deterministic



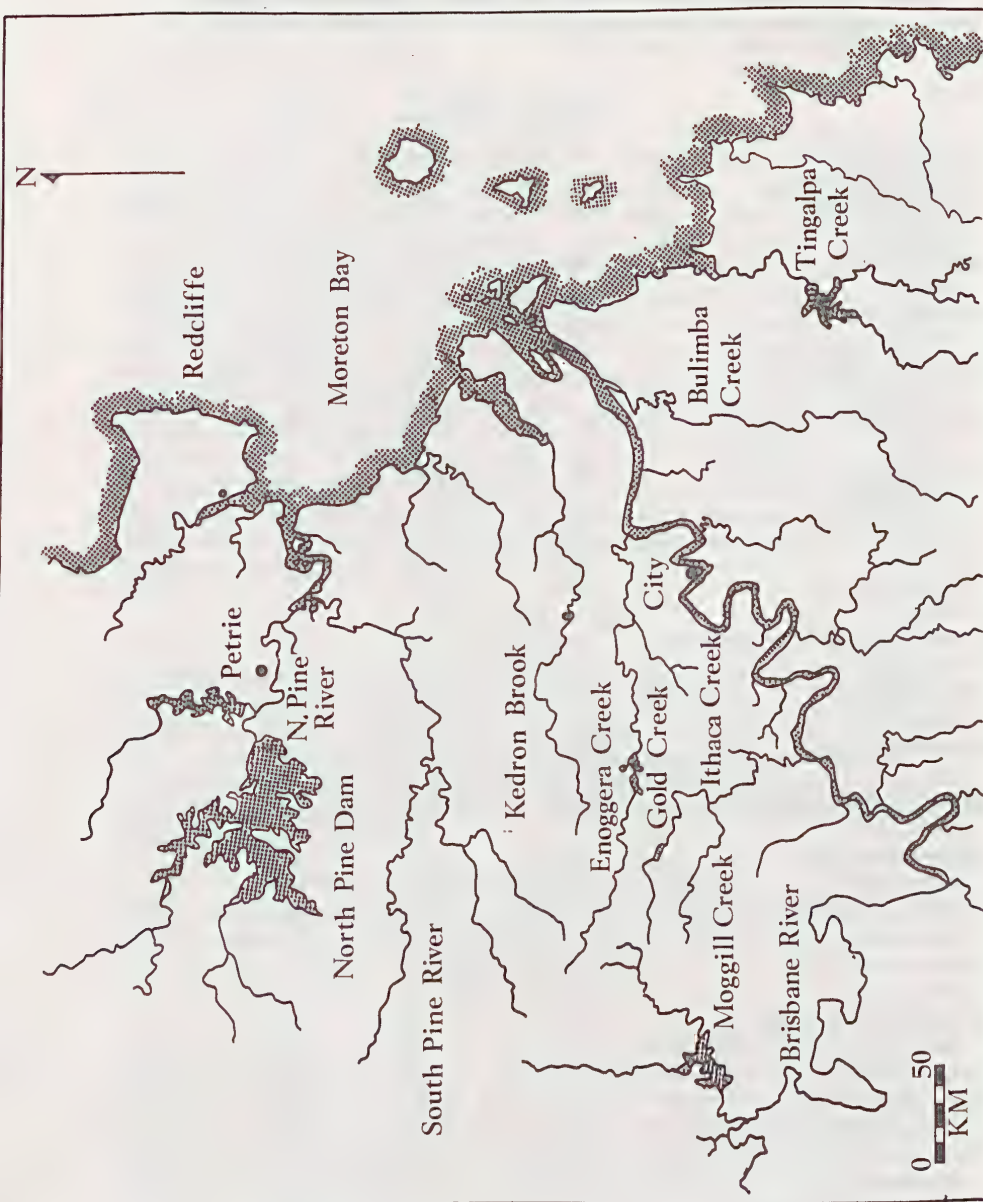


Figure 1: Major creeks and rivers of the Brisbane Region  
(adapted from Arthington *et al.* 1983).

Table 1

Number and percentage of survey sites and creeks in the Brisbane Region supporting exotic and native freshwater fish in 1977-78. Exotic species are shown with \* (from Arthington *et al.* 1983).

| Species                                | No of sites occupied | % of sites occupied | No. of creeks occupied | % of creeks occupied |
|----------------------------------------|----------------------|---------------------|------------------------|----------------------|
| <i>Gambusia affinis</i> *              | 68                   | 89.4                | 50                     | 90.9                 |
| (Baird and Girard)                     |                      |                     |                        |                      |
| <i>Xiphophorus helleri</i> *           | 30                   | 39.5                | 19                     | 34.5                 |
| Heckel                                 |                      |                     |                        |                      |
| <i>Hypseleotris galii</i>              | 28                   | 36.8                | 24                     | 43.6                 |
| (Ogilby)                               |                      |                     |                        |                      |
| <i>Ambassis nigripinnis</i>            | 22                   | 28.9                | 19                     | 34.5                 |
| (De Vis)                               |                      |                     |                        |                      |
| <i>Melanotaenia fluviatilis</i>        | 21                   | 27.6                | 15                     | 27.3                 |
| (Castelnau)                            |                      |                     |                        |                      |
| <i>Hypselotris compressus</i>          | 21                   | 27.6                | 18                     | 32.7                 |
| (Kreffft)                              |                      |                     |                        |                      |
| <i>Anguilla reinhardtii</i>            | 19                   | 25.5                | 14                     | 25.5                 |
| Steindachner                           |                      |                     |                        |                      |
| <i>Pseudomugil signifer</i>            | 13                   | 17.1                | 10                     | 18.2                 |
| Kner                                   |                      |                     |                        |                      |
| <i>Tandanus tandanus</i>               | 11                   | 14.4                | 10                     | 18.2                 |
| Mitchell                               |                      |                     |                        |                      |
| <i>Craterocephalus stercusmuscarum</i> | 10                   | 13.1                | 8                      | 14.5                 |
| (Gunther)                              |                      |                     |                        |                      |
| <i>Retropinna semoni</i>               | 9                    | 11.8                | 9                      | 16.4                 |
| (Weber)                                |                      |                     |                        |                      |
| <i>Poecilia reticulata</i> *           | 9                    | 11.8                | 5                      | 9.1                  |
| Peters                                 |                      |                     |                        |                      |
| <i>Gobiomorphus australis</i>          | 8                    | 10.5                | 6                      | 10.9                 |
| (Kreffft)                              |                      |                     |                        |                      |
| <i>Mogurnda adspersa</i>               | 7                    | 9.2                 | 5                      | 9.1                  |
| (Castelnau)                            |                      |                     |                        |                      |
| <i>Xiphophorus maculatus</i> *         | 6                    | 7.9                 | 4                      | 7.3                  |
| (Gunther)                              |                      |                     |                        |                      |
| <i>Anguilla australis</i>              | 5                    | 6.5                 | 5                      | 9.1                  |
| Richardson                             |                      |                     |                        |                      |
| <i>Philypnodon grandiceps</i>          | 3                    | 3.9                 | 1                      | 1.8                  |
| (Kreffft)                              |                      |                     |                        |                      |
| <i>Philypnodon</i> sp.                 | 3                    | 3.9                 | 3                      | 5.5                  |
| <i>Puntius conchoni</i> *              | 2                    | 2.6                 | 1                      | 1.8                  |
| (Hamilton Buchanan)                    |                      |                     |                        |                      |
| <i>Glossamia aprion</i>                | 2                    | 2.6                 | 1                      | 1.8                  |
| (Steindachner)                         |                      |                     |                        |                      |
| <i>Craterocephalus marjoriae</i>       | 1                    | 1.3                 | 1                      | 1.8                  |
| (Whitley)                              |                      |                     |                        |                      |
| <i>Nematalosa erebi</i> (Gunther)      | 1                    | 1.3                 | 1                      | 1.8                  |
| <i>Carassius auratus</i> *             | 1                    | 1.3                 | 1                      | 1.8                  |
| Number of sites surveyed               | 76                   |                     |                        |                      |
| Number of creeks surveyed              |                      |                     | 55                     |                      |

regulation of community structure, the notion of a river system as a continuum from headwaters to mouth, the intriguing phenomenon of invertebrate drift and its significance in the lives of insects and other animals. Finally, undisturbed creeks can serve as a baseline or control against which to measure the effects of disturbance and water pollution.

### **Educational Value**

The teaching of earth and life sciences requires a supply of material for laboratory study and access to field study sites, as well as treatment at the theoretical level. The close proximity of urban creeks to centres of population and to schools and tertiary institutions is one of their particular advantages. Beyond education in the formal sense there is tremendous potential for informal instruction and involvement of all age groups within the community. For instance in Brisbane the Scout Association bases a number of its environmental activities and awards on project work in aquatic habitats (Arthington 1981). The Australian Littoral Society has stimulated a surge of community interest in the restoration of urban creeks through its creek revegetation programme. Since its inception in 1979 as part of the Brisbane City Council's recreational development programme, this revegetation project has led to the establishment of 11 community action groups working to restore urban creeks in Brisbane. There can be no doubt that this kind of community involvement promotes awareness of the natural environment, of ecological principles and of the need to restore and conserve habitats and their biota.

### **Recreational Value**

Urban creeks have long been the focus of the leisure time of children, be they pristine or polluted. Creeks around Brisbane are used for swimming, boating, fishing, bush-walking, bird-watching and picnicing. The Brisbane City Council has fostered these uses of urban creeks by providing picnic areas, barbecues, facilities and easy access with adequate parking. More active forms of recreation have also been observed in the vicinity of creeks, eg. horse riding, bike and buggy racing and cross-country hiking.

### **Effects of Urban Development on Creek Biota**

Two case studies in Brisbane will serve to illustrate the range of effects that urban development and water pollution may have on the fauna of urban creeks.

#### **Effects on Fish**

In Kedron Brook and Enoggera Creek (Fig. 1) the number of species of native fish has been found to decrease from the upper reaches where the creek environment is largely undisturbed, to the lower reaches in urban and industrial areas. This trend has been observed in other parts of the world (eg. Deacon *et al.* 1964, Tramer and Rogers 1973, Moyle and Nichols 1973). In contrast, fish diversity in undisturbed creeks usually increases from headwaters to lower reaches (eg. Harrell *et al.* 1967, Horwitz 1978, Cadwallar 1979). This increase in diversity is correlated with increasing water depth, increasing habitat diversity and higher productivity (eg. Harrell *et al.* 1967, Whiteside and McNatt 1972, Horwitz 1978). In Brisbane two factors are associated with the decrease in fish diversity as creeks enter urban and industrial areas – changes in the aquatic environment and increasing abundance of exotic fishes such as the mosquito



fish, *Gambusia affinis*. My studies strongly suggest that changes in the aquatic environment have affected the distribution and abundance patterns of some native fishes. The growth of exotic grasses such as para grass along waterways and into creek channels has reduced the extent of open water habitat in the lower reaches of many creeks. Fish that prefer to feed in open water have been affected by loss of this type of habitat eg. the rainbow fish and the smelt. The destruction of aquatic vegetation by siltation, dredging, deposition of rubbish and land fill by riparian landowners and by pollution has affected native fish that feed and spawn amongst vegetation eg. the hardyhead and blue eye (Arthington *et al.* 1983). The native gudgeons do not seem to be adversely affected by these alterations to the aquatic environment and are still abundant in many urban creeks except in the presence of large numbers of mosquitofish. This suggests a biological interaction between some species. The mosquitofish takes 90% of its food items from the water's surface while *Hypseleotris galii* feeds almost entirely on benthic invertebrates. Thus the interaction between these species is not likely to be competition for food but predation or attack and fin-nipping leading to death of the native species.

#### Effects of Sewage Effluent on Benthic Invertebrates

The Bulimba Creek study (Arthington *et al.* 1982) has shown that sewage effluent released into the creek substantially reduced the species richness of the benthic invertebrate community, the drift and the adult Odonata immediately downstream from the outfall of wastes from the sewage treatment plant. This creek is contaminated by residual chlorine used in the disinfection of the treated sewage. Metals in the water may contribute to mortality of invertebrates and there may be synergistic effects involving dissolved oxygen deficiency, metals and chlorine. Within the 10 km section of the creek examined, the benthic invertebrate fauna did not "recover" (ie. return to the faunal diversity recorded at control sites).

#### Some Management Problems in Urban Creeks

There are many dimensions to the problems of creek management in urban areas, particularly when multiple uses of creeks are proposed. One example will suffice to illustrate this. The discharge of wastes from sewage treatment plants into urban creeks in Brisbane has a pronounced effect on the annual flow regime. Year-round flow may be maintained in creeks which would normally be reduced to a series of stagnant, isolated pools during the dry Queensland winter (Arthington *et al.* 1982, Milligan pers. comm.). Continuous flow may thus enhance the recreational value and general aesthetic appeal of urban creeks. Yet the discharge of water of poor quality, contaminated with toxic materials and residual chlorine has severe effects on aquatic biota. The chlorination of sewage wastes reduces the risk of intestinal diseases, and in this sense contributes water quality and amenity value, but for some people the loss of faunal diversity virtually destroys the recreational value and aesthetic appeal of an aquatic system. This has been recognised by the Water Quality Council of Queensland, which carefully weights up the need for chlorination of sewage wastes that are to be released into ecologically sensitive areas.

Multiple uses of urban creeks need not be incompatible but management strategies are needed to evaluate aquatic resources and to set management constraints and priorities at the level of Local and State Governments. In Brisbane the preparation of a Conservation Atlas has provided a foundation for sound, long-term conservation and management of aquatic and other resources of the region.

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## WATER QUALITY MANAGEMENT AND THE ECOLOGICAL NATURE OF RIVERS

by

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### Abstract.

There are increasing pressures for ecologically-based river management. Currently river and water quality management are based on deterministic views of freshwater ecosystems. The nature of communities in rivers is examined and from this comes the emerging view that stream communities may be more individualistic than organismic and more stochastically than deterministically controlled. If this view proves correct, then there will need to be a revision in the guidelines for river management.

### Introduction

In this paper I will initially examine how the underlying philosophies used in water quality management are closely linked to the current limnological dogma concerning the nature of communities in freshwater ecosystems. I then raise the speculation that the currently accepted perception of the ecological nature of river communities may have to be revised and that this revision could result in major changes in the management of rivers.

In Australia, and many other countries, the criteria for the management of water quality are specified for particular purposes or beneficial uses of the water body. The criteria refer to the scientific yardsticks upon which decisions or judgements are made concerning the ability of water to support a designated beneficial use and are defined to meet certain objectives — the levels of water quality indicators designed to protect a range of beneficial uses selected in the light of social, economic and political factors.

“Beneficial use” means a use of the environment or any element or segment of the environment that is conducive to public benefit, welfare, safety or health and which requires protection from the effects of waste discharges, deposits or energy and waste emissions. In Victoria, for example, thirteen beneficial uses of water are recognised [Environment Protection Authority 1983]:

1. potable water supply
2. agricultural water supply
3. industrial water supply
4. hydro-electric power generation
5. navigation and shipping

6. recreation
7. production of edible fish and Crustacea
8. shellfish culture and harvesting
9. maintenance of aquatic ecosystems
10. maintenance of modified aquatic ecosystems
11. maintenance of water-associated wildlife
12. recharging of aquifer
13. scientific and educational uses

Most uses are compatible — some are not, e.g. hydro-electric power generation and maximum protection of aquatic ecosystems.

The criteria are based upon indicators to assess the adherence of particular waters to beneficial use objectives established for them. In the case of off-stream uses, for example potable water supply, physical, chemical and microbiological indicators have been devised for meeting the objective. These indicators for potable water supply meet strict deterministic criteria. Generally the same applies for other off-stream uses, e.g. industrial and agricultural water supply. In fulfilling criteria for off-stream uses, water of relatively low water quality may be abstracted, stored and treated. It is thus possible by segregation and treatment of specific quantities of water to meet the criteria set for beneficial uses such as potable water supply and the indicators listed probably do reflect water quality accurately. Thus for potable water supplies in Victoria the Environment Protection Authority (1983) lists total coliform bacteria, faecal coliform bacteria, filtrable residue, biological non-cumulative and biological cumulative toxicants, toxicant mixtures, radionuclides, organic toxicants, genetically active materials, nutrients, odour, taints and colours, floatable matter, suspended solids and settleable solids as indicators.

Lotic waters, be they rocky alpine upland streams or highly turbid lowland rivers, represent the major type of water body in Australia. With white settlement there has been an immense increase in the number of lentic water bodies, e.g. farm dams or engineering enigmas such as the Serpentine Impoundment. Until recently, rivers have been viewed as systems to dam, abstract water from, put wastes into, to catch fish from, and to manipulate with the gross techniques of 'river improvement'. In recent years, as evident by such occurrences as the battle for the Franklin, the campaign to "Give the Yarra a go", and the controversy over the ecological demise of the Hawkesbury-Nepean River systems, public opinion has increasingly pressured water management authorities to pay more than token attention to the problems of managing rivers and freshwater ecosystems and to allow long-term maintenance of aquatic ecosystems. In some cases, e.g. Molonglo and Yarra Rivers, there has even been pressure to restore seriously polluted ecosystems. In short, the objective to protect and maintain aquatic ecosystems has become a publicly demanded, legitimate goal of water management authorities rather than a vague area of pious hopes.

### River ecosystems

When considering rivers it should be recognized that they are open ecosystems. By this I mean those that rely heavily upon nutrients and energy from allochthonous sources and which, in their dealing with inputs of nutrients and energy, export a significant amount of energy and nutrients. Thus, sound and wise management of river ecosystems must entail also close management of the catchment for it is the state of the catchment and the prevailing climate of that catchment that influences much of what eventually enters the river. Little

can be done to manage the climate, but there is considerable scope to manage the activities in the catchments. I think that most water managers recognize this truth; however, some evade the responsibilities arising from this truth, while others attempt to come to terms with the truth but are thwarted by the highly resilient, complex and resistant networks that make up competing bureaucracies.

Rivers are best regarded as open ecosystems, while lakes are often considered as closed ecosystems (even though we know that lakes do exchange energy and matter). The major, and obvious, feature of rivers is that they have a directionality which lakes do not. Changes in an upstream reach of a river are likely to have effects downstream, but rarely will the reverse situation occur. This implies that nutrients and other matter will spiral downstream (viz. Elwood et al. 1983) which contrasts sharply with the familiar cycles and loops devised for lentic ecosystems. Inputs, such as chemicals or leaf litter, are likely to have shorter residence times in streams compared with lakes. Furthermore, sections of rivers may respond to changes in inputs by accommodating a small portion and exporting the major part.

At any time, the structure and functioning of river ecosystems are dependant on the quality and nature of inputs of matter from meteorological, geological, and biological sources. The meteorological input of water is most significant of these inputs. Fluctuations in flow have an overriding effect on structure and function of components of stream ecosystems, i.e. periphyton, macrophytes, benthic invertebrates and fishes. In some parts of the world the meteorological input may fluctuate predictably, whereas in much of Australia rainfall may fluctuate widely and is largely unpredictable. McMahon (1982) has convincingly shown that Australian rivers are markedly different from those elsewhere in the world because of their greater variability of discharge. The consequences of this variability of stream flow for the biota are unclear for Australian systems, but overseas studies have shown that droughts and floods can have immense biotic effects (viz. Hynes 1970, Fisher 1983). As a result of these fluctuations, streams are not only dynamic systems but are also likely to be in a non-equilibrium state.

### Stream community concepts

There are four ways of looking at communities. The organismic community concept, derived from the work of the pioneer plant ecologist, F.C. Clements, assumes that the community is made up of component individuals and species in very much the same way as organs are part of an organism's body. As Clements, (1935) put it "The community is a complex organism of a wholly different order from the individual plant or animal, but, nevertheless, an organic entity with functions and structure. As a whole it is not merely greater than the sum of its constituent species and individuals, but these in turn are something different in the community from what they are when detached from it." Strong biological interactions are envisaged to operate in such communities (Richardson 1979, 1980).

The opposite concept, that of the individualistic community, comes from another eminent American plant ecologist, H.A. Gleason. In this concept, the community is seen as a collection of species that simply happen to exist together through converging accidents of space, time and similar environmental needs (Richardson 1980). Gleason (1926) stated emphatically that a community "is not an organism, scarcely even a unit ..... but merely a coincidence." The community does not therefore resemble in any evident way the highly integrated obligatory partnerships of specialized elements of the organismic community concept.



Two other ways of considering communities are from the deterministic and the stochastic viewpoint (viz. Grossman 1982, Grossman *et al.* 1982). A deterministic community is conceived of as a collection of species in equilibrium, with a consequent predictable structure. The persistence of species, the resistance to change of the community and the level of biological interactions within the community, are all high. A stochastic community is conceived as being a collection of species in a non-equilibrium state changing with environmental changes. With environmental changes, the resistance is low, and there are the changes in species composition. The outcome of these changes in terms of community structure is probabilistic rather than singular or deterministic. These two types of communities are at opposite ends of a probability continuum (Glasser and Wiegert 1983).

There is a detailed and extensive body of literature which stress the idea that stream communities are primarily determined by the nature of, and variations in time and space of, physico-chemical factors rather than the strength of biological interactions (viz. Hynes 1970). It is also evident that, in terms of physio-chemical factors, individual species have individual requirements (e.g. Reice 1980, 1983; Orth and Maughan 1983; Townsend *et al.* 1983).

Stream insects are largely detritivores. About 31 per cent of the extant species on earth consists of carnivorous and decomposer insects, mostly the latter (Strong 1983). It seems that biological interactions are much less important than physico-chemical forces in structuring decomposer insect communities (Strong 1983). Thus, until clear evidence is produced showing that biological interactions are important in structuring whole stream communities, it is most parsimonious to adopt the view that stream communities are individualistic rather than organismic.

Grossman *et al.* (1982) have produced evidence suggesting that a stream fish assemblage is a stochastically rather than deterministically organized one. Evidence reviewed by Grossman *et al.* (1982) and recent work, including our own at Monash, suggest that lotic invertebrate communities may be similarly organized.

If lotic communities are stochastically organised, with species behaving in an individualistic fashion, then these ideas run against the pre existing orthodoxies of lotic ecology. The River Continuum Concept (RCC) of Vannote *et al.* (1980) exemplifies these orthodoxies: the components of riverine ecosystems are seen as being controlled deterministically by a small group of inputs, notably organic matter, and by stream morphometry. Unfortunately, the evidence collected by the proponents of the RCC themselves in the U.S.A. (Minshall *et al.* 1983) and by others (e.g. Winterbourn *et al.* 1981) elsewhere do not fit all the predictions of the RCC. It seems that the individualistic, stochastic nature of river communities is becoming evident to the proponents of the RCC since they are now invoking a collection of "reset" and "modifying" factors, such as the effects of tributaries and different catchment histories, to make the RCC fit each suite of local conditions (Minshall *et al.* 1983, Bruns *et al.* 1984). Thus a generalization may, by the invocation of qualifying factors, be broken down into a series of special cases. In the RCC each section of a river ecosystem is regarded as being controlled in the same deterministic way by a suite of selected variables. It is possible that each section of a river ecosystem may be regulated in a different way and that some sections may be more stochastically regulated than other sections which may be more deterministically organized.

## Implications for stream management strategies

If the communities that make up river ecosystems are individualistic and stochastic a number of difficult questions arise. Two are:

1. How does this view of rivers fit with dominant limnological thought and with current river management practices?
2. How can we understand such systems as rivers in order to manage them?

In considering the first question it is evident that the protection strategies devised by regulatory authorities are very deterministic. An illustration of this comes from Victoria. In this State, State Environmental Protection Policies (S.E.P.P.) are devised for rivers, which after public comment, set out management objectives based on a number of criteria. There is a marked lack of biological criteria used in these S.E.P.P.'s and the development of suitable biologically-based criteria should be a high research priority of water regulatory authorities. The S.E.P.P.'s have been developed for a number of rivers. Some, like the La Trobe, have relatively small variations in discharge and others, like the Wimmera, have immense variations in discharge. In the S.E.P.P.'s variations sections of rivers are given particular levels of protection which are defined in a very deterministic way. For example, in the Wimmera River potable water supplies and water storages are given a medium level of ecosystem protection and the river itself is given a minimum level of protection (Environment Protection Authority of Victoria 1984). For Level III Protection, the medium level of protection, the level of non-cumulative toxicants should not exceed

$$N + 0.5 (T - N)$$

N = natural background level

T = threshold concentration

For Level IV Protection — the minimum level of protection — there should be “unimpaired functioning of the ecosystem” and water quality can be degraded to the threshold level of harmful effects. Leaving aside the immensely difficult question of how the unimpaired functioning of the ecosystem is determined, it is very evident that deterministic criteria are being imposed on probabilistic, individualistic ecosystems such as rivers.

The reasons for such determinism are not merely pragmatic. They lie partly in the history of limnology. Reading through books on limnology I have been struck by the deterministic tone of textbook limnology. One is also struck by the plethora of attempts to account for biological phenomena by physico-chemical, reductionistic explanations that do not take account of probabilistic events and phenomena. This deterministic view has probably arisen from the emphasis of limnological research on lentic ecosystems. Lentic ecosystems are largely “closed” ecosystems which accommodate rather than export disturbing forces and are much more predictable in their behaviour than open systems like rivers. The deterministic findings from studies of lake behaviour have engendered the sense that the same type of processes operate in rivers.

Coincident with the emergence of the deterministic view in limnology was the development of a very deterministic way of looking at pollution. This is no better exemplified than by the "saprobiensystem" of Kolkwitz and Marsson (1902) which sought to generalize what is difficult to generalize, namely the response of the fauna of a river to pollution. This approach is univariate and deterministic rather than being multivariate and probabilistic in approach, which I maintain would be the better way to predict the impact of pollution on rivers.

The univariate and deterministic way of assessing pollution was also very evident in the advocacy of diversity indices. Here multivariate data are reduced to univariate indices. In spite of a growing awareness of the short-comings of such approaches to pollution as the "saprobiensystem", remnants of determinism still persist. One such remnant that is being hotly debated at present is the concept of "assimilative capacity". This concept has many meanings, but out of the literature the following definition can be distilled: the assimilative capacity of an ecosystem, e.g. river, is the ability to assimilate degradable wastes by changing its structure and function but without losing its integrity. A major advocate of assimilative capacity, J. Cairns, jr. (viz. 1981), has argued that the ecosystem has to change to allow ecologists to detect the limits of the assimilative capacity and that up to these limits the changes occur without the ecosystem losing its integrity. This concept underpins a lot of regulation of discharge by pollution management authorities.

There are at least four faults in the concept of assimilative capacity. These are:

1. although the concept accepts the dynamic nature of stream ecosystems, it rests on untested deterministic generalizations;
2. the concept assumes that in the determination of the assimilative capacity, appropriate parameters can be selected to measure the stress imposed by the pollution on the ecosystem;
3. the concept assumes that, to the limits of a determinable threshold, the stresses imposed by the pollution on the ecosystem are reversible; and
4. the concept assumes the existence of an entity or property called "ecosystem integrity".

This is not defined and may not be definable. With what criteria do we measure "ecosystem integrity"? ["Ecosystem integrity" is a very organismic community concept.]

In my view the question of how one assesses ecological integrity in a river ecosystem needs to be resolved before concepts like assimilative capacity are applied, if they ever can be.

It is interesting to consider that the impact of pollution may change the properties of the ecosystem such that the lotic communities affected may be converted from being probabilistic or stochastic communities into deterministic communities, e.g. in a river subjected to organic pollution. It is easier to predict the species present in a zone of severe organic pollution than it is in an unpolluted stream section.



## Two research strategies for rivers

If rivers are individualistic in nature, how can we come to understand such systems? How can we make predictions about their behaviour? These questions are crucial to allow management authorities to protect riverine ecosystems. Two research strategies come to mind: (a) to monitor individual perturbations, and (b) long-term monitoring. It is well known that perturbations, such as pollution discharges, dams, river improvement, are imposed on rivers. Some of these are, as Bender *et al.* (1984) point out, "pulse" perturbations, and some are "press". A single episode of pollution, e.g. accidental discharge, may be a "pulse" perturbation, while a consistent discharge is a "press" perturbation. Ecosystems respond differently to such perturbations. From observing a perturbation — before, during, and after — we may gain an insight into the structure of river communities, their resistance and their resiliency. Thus I come to an oft-sounded plea that management authorities responsible for rivers subject to perturbations, commission or encourage extensive multi-parameter (abiotic and biotic) monitoring of perturbations — before, during and after — and make sure that all the data are analyzed to provide us with an account of what happened.

The second strategy, which can be coupled with the first, is to encourage long-term, detailed monitoring of selected natural and modified aquatic ecosystems. Professor G.E. Likens (of Hubbard Brook fame) recently addressed this need in his 1983 Presidential Address to the Ecological Society of America (Likens 1983). He pointed out that in ecology, as in all sciences, we need to know how the basic units of study behave — but "unfortunately, because of the complexity of natural systems, it may take longer in ecology than in other disciplines to build up a useful background of information whereby enough insight is gained to develop meaningful hypotheses". Likens also pointed out that vast amounts of routine data have been collected, stored and then forgotten and that such mindless activity has given long-term research a bad name. The deficiency occurs because in many cases there were no clear initial objectives or experimental designs set for the use of the data. Devising objectives will need, in Likens' view, "our very best scientific talent ..... to achieve any measure of success in this regard". He further states, and this brings me back to 'assimulative capacity' and ecosystem protection, "it is not possible to ask a question or model a system relative to what is a 'typical response' or what is a 'typical pattern' in ecology without an understanding of the system based on a long record of observation and analysis". The linking of models and the actual behaviour of the ecosystem in question involves long-term research and this particularly applies to systems which are as variable as rivers. The commissioning and funding of long-term research in Australia would require a drastic change in the attitudes of those who administer research funds. Long-term research, especially long-term limnological research, sits as the lowest of the low priorities of research funding in this country. As Likens (1983) points out, "to be fundable, most proposals seeking public funds must be 'safe' — safe in the sense that the topic and the methods are consistent with the prevailing wisdom or even the current fad", and the current wisdom and fashion is against long-term research. Let us hope that the current immense imbalance toward short-term funding is re-assessed.

In summary, I have attempted to show that there are close links between basic ecological research and ecologically-based management. However, these links are at present tenuous, not only due to a lack of research but also because of a tradition of viewing aquatic ecosystems in a deterministic way. The study of

community and ecosystem ecology today is an exciting field — this excitement is very evident in freshwater ecology; we must guard against advocating unreal or untestable models.

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## LABORATORY REARING OF AUSTRALIAN ELMID LARVAE (ELMIDAE: COLEOPTERA)

by

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### Abstract

Last instar larvae collected throughout Australia were reared on moist sand in petri dishes. Temperature controls were not used. Twenty-eight species from five genera emerged as adults, representing a success rate of 26% (186 adults from 706 larvae).

### Introduction

Adults and larvae of Elmidae coexist, often in large numbers, in most permanent Australian streams except those of south-west Western Australia. One Hundred and two elmids species have been described in nine genera — *Austrolimnius* (52), *Notiulus* (16), *Simsonia* (15), *Kingolus* (11), *Coxelmis* (3), *Hydretus* (2), *Stenelmis* (1), *Hydora* (1), and *Stetholus* (1). The major works on Australian Elmidae are limited to the taxonomy of adults (Carter & Zeck 1929 and Hinton 1965). General notes are given by Britton (1970) and Williams (1980). Works on the larvae are restricted to Bertrand (1972) with diagrams of and unidentified elmids species, and Davis (1942), a description of the larva of *Coxelmis novemotata*.

The generic and specific identification of elmids larvae has been determined by workers overseas using several methods. These techniques include field association (Sanderson 1953 and Hinton 1940) laboratory tank systems (White & Jennings 1973, White 1978 and Davis 1942), and field collection of live pupae and subsequent rearing (Le Sage & Harper 1976(a), Le Sage & Harper 1976(b), Olmi 1978 and Hinton 1940).

A new method of live rearing of larvae to the adult is described below. During a two year period approximately twenty-eight species in five genera, *Austrolimnius*, *Coxelmis*, *Kingolus*, *Notiulus* and *Simsonia* were successfully reared. Descriptions of larvae associated with described adults will be reported separately.

### Method

Last instar elmids larvae were collected from streams and lakes in Victoria, Tasmania, Queensland, New South Wales, Western Australia and the Northern Territory. These can be identified in the field by the presence of spiracles, dark colour and size.

The larvae were placed in petri dishes (9 cm diameter) half filled with a mixture of fine to coarse river sand which had been heat sterilized and washed. Petri dishes were stacked on a bench in the laboratory. Artificial heating (24° – 25°C) during winter proved ineffective in promoting pupation, and thereafter no temperature control was used. No attempt was made to try to locate pupae within the sand, but the dishes were periodically checked for emergence of adults. No feeding was attempted, and the only maintenance required was keeping the sand moist (but not wet) with either river or tap water. Use of a covering of sphagnum moss was found to make location of pupal and larval skins difficult and was discontinued.

The pupal chamber containing exuviae was located either by following the emergence tunnel which was sometimes visible as a small hole in the sand, or by elutriation with water. The adults were mounted on card pins and the associated skins preserved in alcohol.

## Results

During the period from November 1977 to November 1980, a total of 706 elmid larvae were used for rearing. The majority of larvae were captured in Victoria with representatives from other Australian States. Emergence success is recorded in Table I. 186 adults from 28 species emerged (Table 2) resulting in a success rate of 26%.

Table 3 summarises the rearing data. The month of emergence, laboratory temperatures and number, genera and origin of larvae are presented.

**TABLE 1: Location of Capture of Larvae and Emergence of Adults.**

| State Collected    | No. of Specimens | No. adults emerged |
|--------------------|------------------|--------------------|
| Victoria           | 518              | 123                |
| Tasmania           | 51               | 20                 |
| Queensland         | 72               | 36                 |
| Northern Territory | 14               | 4                  |
| New South Wales    | 4                | 0                  |
| Western Australia  | 47               | 3                  |
| Total:             | 706              | 186                |



TABLE 2. List of Species successfully reared.

*Notriolus allynesis*  
*N. maculatus*  
*N. quadeoplagiatus*  
*N. victoriae*  
*Notriolus* new sp.

*Simsonia brooksi*  
*S. hopsoni*  
*S. tonnoiri*

*Austrolimnius mormo*  
*A. waterhousei*

*Kingolus tinctus*  
*Kingolus* new sp.

*Coxelmis v-fasciata*  
*C. novemnotata*

Undetermined species

7 *Simsonia* spp.  
 4 *Kingolus* spp.  
 3 *Austrolimnius*

Larvae of all species formed a pupal chamber in the sand and *Simsonia brooksi* also pupated in the sphagnum moss when it was available. The only observation made on duration of the pupal stage was for one specimen of *Simsonia hopsoni* which was observed as a pupa for at least ten days.

The larvae are able to survive long periods in humid conditions without running water. If they feed in the sand it is presumed to be on fungi, bacteria, and other micro organisms that may develop within the petri dishes. One specimen of *Austrolimnius* sp. survived for fourteen months before emerging as an adult. A specimen of *Simsonia tasmanica* remained alive for 14 months without pupation occurring.

The times between collection of last instar larvae and laboratory emergence of adults were compared and the following groups were distinguished (Table 4):

- (i) those larvae captured in spring or early summer and emerging in the same summer; (61%)
- (ii) (a) those larvae captured in summer, overwintering in the laboratory and emerging in the following spring (10%)

TABLE 3: Monthly records of number of genera of elmids adults emerging, laboratory temperature, and larval localities.

| MONTH         | EMERGENCE<br>No. of<br>Specimens | Genera   | MONTHLY TEMPERATURE<br>(°C) |      |      | LOCALITY,       |
|---------------|----------------------------------|----------|-----------------------------|------|------|-----------------|
|               |                                  |          | Mean                        | Max. | Min. |                 |
| 1977 November | 1                                | S        |                             |      |      | Victoria        |
| 1978 February | 3                                | A,N      |                             |      |      | Victoria        |
| March         | 28                               | C,K,N,S, | No Records                  |      |      | Victoria        |
| April         | 1                                | S        |                             |      |      | Victoria        |
| May           | 1                                | A        |                             |      |      | Victoria        |
| June          |                                  |          | 19.9                        | 22.8 | 18.4 |                 |
| July          |                                  |          | 18.1                        | 19.0 | 17.0 |                 |
| August        |                                  |          | 17.9                        | 19.2 | 16.8 |                 |
| September     |                                  |          | 20.0                        | 21.2 | 18.5 |                 |
| October       | 7                                | K,S      | 21.7                        | 24.4 | 19.5 | Victoria        |
| November      | 3                                | K,N,S    | 22.5                        | 25.0 | 20.5 | Victoria        |
| December      | 5                                | K,S      | 22.3                        | 23.8 | 21.1 | Victoria        |
| 1979 January  | 42                               | A,C,N,S, | 24.7                        | 27.0 | 23.2 | Vic., Qld.      |
| February      | 6                                | A,N      | 24.9                        | 27.1 | 22.2 | Victoria        |
| March         | 12                               | A,K,N    | 24.0                        | 25.6 | 22.8 | Vic., Qld.      |
| April         | 1                                | N        | 22.6                        | 24.0 | 21.4 | Victoria        |
| May           | 2                                | A,N      | 20.1                        | 23.4 | 18.4 | Victoria        |
| June          |                                  |          | 19.8                        | 21.7 | 18.4 |                 |
| July          |                                  |          | 19.5                        | 21.5 | 18.0 |                 |
| August        | 18                               | K        | 18.9                        | 20.2 | 17.5 | Tasmania        |
| September     | 2                                | A,S      | 20.1                        | 21.9 | 18.4 | Vic., Qld.      |
| October       | 25                               | K,S      | 21.2                        | 23.5 | 19.4 | Vic., Qld., NT. |
| November      | 11                               | K,S      | 23.1                        | 24.1 | 21.5 | Vic., Qld., NT. |
| December      |                                  |          | 23.7                        | 25.0 | 22.4 |                 |
| 1980 January  | 2                                | S        | 24.1                        | 26.0 | 22.4 | Qld.            |
| February      | 1                                | A        | 24.3                        | 26.7 | 21.6 | Victoria        |
| March         | 4                                | A        |                             |      |      | Vic., NT.       |
| April         | 5                                | A,S      | No Records                  |      |      | Victoria        |
| May           | 3                                | A        |                             |      |      | W.A.            |
| November      | 3                                | N        |                             |      |      | Victoria        |

\*A: *Austrolimnius*, C: *Coxelmis*, K: *Kingolus*, N: *Notriolus*, S: *Simsonia*.

TABLE 4. Records of numbers and genera of elmid adults relating month of capture to month of emergence (Nov. 1977 to Nov. 1980) and larval localities.

| Month of emergence | No. of Months since capture | No. of specimens | Genera* | Locality State     |                  |
|--------------------|-----------------------------|------------------|---------|--------------------|------------------|
| (i)                | January                     | 1                | 28      | C,N,S              | Victoria         |
|                    |                             | 2                | 10      | A,C,S              | Victoria, Q'land |
|                    |                             | 3                | 1       | S                  | Queensland       |
|                    |                             | 4                | 1       | N                  | Victoria         |
|                    |                             | 5                | 2       | N,S                | Victoria, Q'land |
|                    |                             | 6                | 2       | C                  | Victoria         |
|                    | February                    | 2                | 2       | A,N                | Victoria         |
|                    |                             | 3                | 4       | N                  | Victoria         |
|                    |                             | 4                | 1       | A                  | Victoria         |
|                    |                             | 5                | 1       | N                  | Victoria         |
|                    | March                       | 1                | 4       | N                  | Victoria         |
|                    |                             | 2                | 18      | N,S                | Victoria         |
|                    |                             | 3                | 14      | A,C,K,N            | Victoria         |
|                    |                             | 4                | 3       | N                  | Victoria, Q'land |
|                    |                             | 6                | 4       | N,S                | Victoria, N.T.   |
|                    |                             | 7                | 3       | N                  | Victoria         |
|                    | April                       | 2                | 4       | S                  | Victoria         |
|                    |                             | 4                | 6       | N,S                | Victoria         |
|                    | May                         | 3                | 1       | N                  | Victoria         |
|                    |                             | 4                | 1       | A                  | Victoria         |
|                    |                             | 6                | 1       | A                  | Victoria         |
|                    |                             | 7                | 3       | A                  | W. Aust.         |
|                    | December                    | 1                | 4       | A,S                | Victoria         |
|                    |                             |                  |         |                    |                  |
| (ii)a              |                             |                  |         |                    |                  |
| February           | 12                          | 1                | A       | Victoria           |                  |
| March              | 12                          | 1                | A       | Victoria           |                  |
| April              | 14                          | 1                | A       | Victoria           |                  |
| September          | 10                          | 1                | A       | Victoria           |                  |
| October            | 6                           | 1                | K       | Victoria           |                  |
|                    | 7                           | 5                | S       | Victoria           |                  |
|                    | 9                           | 1                | K       | Victoria           |                  |
| November           | 7                           | 1                | A       | Victoria           |                  |
|                    | 8                           | 5                | N,S     | Victoria, Tasmania |                  |
| December           | 10                          | 1                | K       | Victoria           |                  |
|                    | 13                          | 1                | S       | Victoria           |                  |



|           |   |    |     |            |
|-----------|---|----|-----|------------|
| (ii)b     |   |    |     |            |
| August    | 5 | 18 | K   | Tasmania   |
| (ii)c     |   |    |     |            |
| September | 1 | 1  | S   | Queensland |
| October   | 1 | 1  | S   | N.T.       |
|           | 2 | 22 | K,S | Queensland |
| November  | 2 | 3  | N,S | Victoria   |
|           | 3 | 9  | K,S | Queensland |

\*A: *Austroliminius*, C: *Coxelmis*, K: *Kingolus*, N: *Notriolus*, S: *Simsonia*

(b) those larvae overwintering in the laboratory and emerging in August (10% — this is considerably earlier emergence than that of their counterparts in group (a).

(c) those larvae captured and emerging in the same spring (19%) — these are predominantly specimens from interstate.

### Discussion

The live rearing method described appears to be well suited to the Australian Elmidae. Adults were successfully reared from larvae collected in diverse localities and temperature regimes, and covering the five common genera. The 26% success rate achieved is acceptable considering the advantages of this method which are:

1. minimum time and effort required on maintenance;
2. ease of locating larval and pupal skins for definite determinations;
3. large numbers of larvae from different localities can be reared simultaneously;
4. collections of larvae can be made at any time of the year.

This rearing technique produced very little life history information. However, two tentative conclusions can be drawn.

1. Emergence of adults in the warm months suggests a minimum temperature requirement for pupation and/or an overwintering period for the larvae. Le Sage & Harper 1976(b) found that elmids overwinter as last instar larvae and leave the water in Spring to pupate.

2. Many larvae may be tolerant of major changes in temperature and habitat and able to survive up to 14 months in moist sand.

Most information on life histories of Elmidae has been accumulated by extensive seasonal collections of larvae, pupae and adults in streams. Berthelemy & Ductor (1965) and Berthelemy & De Riols (1965) found larvae in all stages of development together with adults throughout the year. Mature larvae were relatively more abundant in spring, and adults more numerous in summer with metamorphosis occurring in the spring. Le Sage & Harper (1976a) and Matheson (1914) could only find pupae in July and August (northern summer). Last instar larvae of Australian species seem to be present throughout the year and emergence appears to occur over a longer period, that is, both spring and summer.

Le Sage & Harper (1976b) observed that temperature advances or retards the period of pupation in *Stenelmis crenata*. Under Australian conditions, suitable temperatures are probably maintained for longer and result in a less restricted period of emergence.

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## WATER BEETLES OF SALT LAKES NEAR COLAC, VICTORIA

by

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### Abstract

Nineteen species of water beetles were caught in 24 saline lakes near Colac, with *Megaporous howitti*, *Necterosoma penicillatum* and *Enochrus* nr *andersoni* the most widespread. Few species apparently breed in the lakes. This was only a loose inverse relationship between the lakes. Species richness and salinity ranges are about the same as for water beetles in North American saline lakes, but Australian species are endemic and the genera different.

### Introduction

Since the pioneering study by Bayly and Williams (1966) on some saline lakes in southeastern Australia, there has been a number of surveys and ecological studies on the fauna of Australian salt lakes (see reviews by Williams, 1978, 1981). As a result, many ecological data are available for some taxa, especially crustaceans, but for others information is still scant. One such group is the aquatic Coleoptera. Studies to date list only 10 species — the dytiscids *Bidessodes* sp., *Megaporous howitti* (Clark), *Lancetes lanceolatus* Clark, *Necterosoma penicillatum* Clark and *Rhantus suturalis* (MacLeay), the hydrophilids *Berosus australiae* Muls, *Enochrus* nr *andersoni* (Blackburn) *Hydrobius assimilis* Hope, *Hydrophilus latipalpus* Castelnau and the curculionid *Bagous* sp. (Bayly and Williams, 1966; Halse 1981; Lim, 1964; Pollard 1971; Timms, 1973; Walker, 1973), yet reconnaissance of some lakes at Red Rock, near Colac, suggest a much richer fauna. It is the aim of this work to document the diversity and salinity range of beetles in saline lakes near Colac.

### Methods

Twenty four lakes covering a salinity range of 1.3 - 203 g.l<sup>-1</sup> were selected for study in the Colac-Camperdown-Lismore area of the Western District of Victoria (Table 1). Two person-hours were spent in each searching for water beetles with a pond net. In addition to salinity measurements with a conductivity meter, notes were made on the relative abundance of rocks, aquatic plants, and on the roughness of inshore water (waves often hampered searching).

TABLE 1

The study lakes — some environmental factors and the number of beetle species in each.

| Lake                              | Code | Rockiness† | Macrophyte†<br>abundance | Protection† | Salinity<br>g l <sup>-1</sup> | Number of<br>species of<br>beetles |
|-----------------------------------|------|------------|--------------------------|-------------|-------------------------------|------------------------------------|
| Colac                             | C1   | +++        | ++                       | ++          | 1.3                           | 8                                  |
| Purdigulac                        | P    | +++        | ++                       | ++          | 1.4                           | 4                                  |
| Modewarre                         | M    | +          | ++                       |             | 4.0                           | 1                                  |
| Coragulac*                        | C2   | +++        | +++                      | +++         | 4.1                           | 6                                  |
| Loc D* <i>sensu</i><br>Bayly 1969 | D    | ++         | +                        | +++         | 6.0                           | 11 <sup>Ø</sup>                    |
| Coradgill                         | C3   | +++        | +                        | ++          | 7.3                           | 5                                  |
| Kariah                            | K    | +++        | +++                      | ++          | 7.7                           | 9                                  |
| Colongulac                        | C4   | +          |                          |             | 9.7                           | 2                                  |
| Koreetung                         | O    | ++         |                          | +           | 10.6                          | 1 <sup>Ø</sup>                     |
| Gnarput                           | G    |            |                          | +           | 11.0                          | 0                                  |
| Bookar                            | B    | +          | ++                       | +           | 13.3                          | 2                                  |
| Red Rock Tarn*                    | R    | ++         |                          | +++         | 13.4                          | 8 <sup>Ø</sup>                     |
| West Twin*                        | T    | ++         | +                        | +           | 14.8                          | 3                                  |
| East Twin*                        | U    | ++         | +                        | ++          | 16.8                          | 3 <sup>Ø</sup>                     |
| Werowrap*                         | W    | +++        |                          | +           | 20.9                          | 1                                  |
| Gnarlinegurk*                     | N    | +++        |                          | ++          | 24.1                          | 3 <sup>Ø</sup>                     |
| Corangamite                       | C5   | +++        |                          |             | 30.4                          | 2                                  |
| Barney Bolac                      | A    | +          | +                        | +           | 38.7                          | 1                                  |
| 'Missen's L',<br>via Beeac        | -    |            |                          | +           | 82.4                          | 0                                  |
| Terang Goodwitch                  | -    |            |                          | ++          | 103.9                         | 0                                  |
| Terrinallum                       | -    | +          |                          | ++          | 118.8                         | 0                                  |
| Pink                              | -    |            |                          | +           | 142.8                         | 0                                  |
| Tatutong                          | -    | +          |                          | ++          | 203.9                         | 0                                  |

† Determined subjectively on a scale of zero to +++. These designations apply only to conditions at the time and place of collection.

Ø Larvae present (data from Timms, 1983).

\* One of the Red Rock lakes.

In collecting beetles from these lakes a major problem arose in knowing when all the species living in a lake at that time were collected; beetles were often few in number or unevenly distributed or both. Field experience suggested that almost all of the species caught in a lake, were obtained within the first hour of collecting, but occasionally extra species were caught after 1½ hours or even 2 hours. A two-hour time limit was found to be a practical compromise.

The beetles were identified by C.H.S.W. and voucher specimens are now stored in the ecology reference collection at Avondale College.

## Results

Nineteen species were collected from the saline lakes (ie. salinity  $> 3 \text{ g l}^{-1}$ ) in the series; another one was encountered only at  $1.3 \text{ g l}^{-1}$  (Fig. 1.). Three families were represented, with the most common species being the dytiscids *Megaporus howitti* and *Necterosoma penicillatum* and the hydrophilid *Enochrus* nr *andersoni*. Seven species could be regarded as being uncommon in the lakes studied, there being just one record of each (Fig. 1.).

*Necterosoma penicillatum* had the widest salinity range, from  $1.3 - 38.7 \text{ g l}^{-1}$ . *Berosus munitipennis*, *Enochrus* nr *andersoni* and *Megaporus howitti* also had wide salinity ranges. The remaining species probably had much narrower salinity ranges, but in most cases there are too few records to be sure. *Allodesus bistrigatus*, *Helochaeres australi* and *Limnoxenus macer* probably are exceptions, as the 5 records for each are in a limited salinity range.

There was a loose inverse relationship between the number of species per lake and salinity (Table 2). Field experience suggested (see Table 1) that windswept sandy/clayey shorelines harboured few beetles while protected rocky/gravelly/weedy shorelines were the most productive collecting sites.

TABLE 2

Relationship between salinity and the number of beetles species.

| Salinity range<br>( $\text{g l}^{-1}$ ) | Number of<br>lakes | Number of beetles species<br>range | mean |
|-----------------------------------------|--------------------|------------------------------------|------|
| 1 - 3                                   | 2                  | 4 - 8                              | 6    |
| 3.1 - 10                                | 6                  | 1 - 11                             | 5.7  |
| 10.1 - 20                               | 6                  | 0 - 8                              | 2.8  |
| 20.1 - 40                               | 4                  | 1 - 3                              | 1.75 |
| 40                                      | 5                  | 0                                  | 0    |

## Discussion

The 19 species recorded here, added to those listed only in the literature (shown in Fig. 1) make 25 species known so far for Australian salt lakes (salinity  $> 3 \text{ g l}^{-1}$ ). The most characteristic species in southeastern Australia, as judged from literature records and present data, are *Necterosoma penicillatum*, *Enochrus* nr *andersoni* and *Megaporus howitti*, in that order.



It is possible that many species on the list are not normal inhabitants of saline lakes, but are included because of the chance, temporary presence of one or a few individuals in a lake at the time of collection. In this respect the two specimens recorded in Lake Gnotuk (Timms, 1973) were the only ones seen in four intense searches and in 32 other visits to the lake over three years. Thus if all records based on single occurrences are removed from the list, it would be reduced to 14 species. The best test of the usual presence of a species in a lake would be if larvae were present. Certainly *Necterosoma pencillatum* breeds in Lake Werowrap (salinity  $< 20 \text{ g l}^{-1}$ ) (Walker, 1973) and Timms (1983) records *Necterosoma* sp. larvae (salinity range  $6\text{--}24 \text{ g l}^{-1}$ ) and *Berosus* sp. larvae ( $6\text{--}15 \text{ g l}^{-1}$ ) in the benthos of these same lakes, so that at least these two genera are halophilic.

The 25 species recorded thus far from Australian salt lakes belong to four families — the Dytiscidae and Hydrophilidae are of similar importance with 12 and 11 species respectively and the Sphaeridae and Curculionidae are each represented by one uncommon species. There are no indications of the other common and widespread water beetle family, the Gyrinidae, being found in saline lakes. Among the dytiscids, almost all the species in the saline lakes are widely distributed in Australia, usually in fresh water (see Watts, 1978). The same probably applies to the hydrophilids, but definitive data are lacking. For at least one species, *Allodessus bistrigatus*, presence in the Colac saline lakes provides a significant extension of its known range ('inland Australia' and 'rare on east coast' — Watts, 1978).

Typically, groups inhabiting saline lakes show an inverse relationship between species richness and salinity (eg. Williams, 1978, 1981). However the relationship for water beetles is tenuous (Table 1), but more apparent

when averages are taken for groups of lakes (Table 2). In the case of water beetles the influence of salinity on distribution is likely to be blurred by habitat requirements. Rocky and weedy littorals seem to be more favourable habitats than wave-swept clayey or sandy shorelines at any given salinity. For instance, L. Kariah had a much richer beetle fauna than nearby and only slightly more saline, Lakes Colangulac and Koreetnung, apparently because the collecting site was more weedy, rocky and protected in L. Kariah than in the other two lakes (see Table 1).

A further factor, anionic proportions in the saline lakes, may be influencing distribution. Bayly (1969) suggested that relatively large amounts of bicarbonate and a high ratio of monovalent to divalent cations in the Red Rock lakes has permitted the penetration of the typically freshwater copepod *Boeckella triarticulata*. In this context, most Red Rock lakes have more beetles than other lakes of similar salinity (Table 1), and furthermore two beetles (*Sphaericus* sp. and *Berosus majusculus*) are restricted to them and other two (*Allodessus bistrigatus*, *Limnoxenus macer*) have their highest salinity record in these lakes. However, it could be argued that the greater species richness in the Red Rock lakes is associated with a more favourable physical habitat (the shores are relatively protected from wave action, are rocky-gravelly and some have dense beds of macrophytes) or perhaps is due to the chance distribution of species easily dispersed as flying adults. In summary, then, the inverse relationship between species richness and salinity is not highly correlated for water beetles, because of the varying and largely undetermined influence of other factors.

There are probably no halobiont water beetles in Australia since all species penetrating saline lakes are known either to live in fresh water (the dytiscids – see Watts 1978) or probably do so (the hydrophilids and the sphacrid). *Necterosoma penicillatum* is the most salt tolerant halophil, reaching salinities of  $92.6 \text{ g l}^{-1}$  (Bayly and Williams, 1966), though the maximum salinity record in the present study was  $38.7 \text{ g l}^{-1}$ . Altogether five species are known to penetrate salinities  $> 30 \text{ g l}^{-1}$ , six species  $> 20 \text{ g l}^{-1}$ , 13 species  $> 10 \text{ g l}^{-1}$  and 25 species  $> 3 \text{ g l}^{-1}$  (see Fig. 1.).

Though insects, including water beetles, are relatively unimportant in Australian saline lakes *vis-a-vis* saline lakes overseas (eg. Geddes *et al.* 1981), there seems to be little difference in the number of species of water beetle involved or in the upper limits reached. Although Rawson and Moore (1944) report 37 species in their study of Saskatchewan saline lakes, most of these were restricted to waters not considered saline here (ie. salinities  $< 3 \text{ g l}^{-1}$ ) and only one species penetrated the salinity gradient to any degree (to  $118 \text{ g l}^{-1}$ ). Scudder (1969) lists two species in highly saline waters of British Columbia and a further three in lakes of lower salinity. Lauer (1963) mentions only one halophilic beetle in his work on two saline lakes in Washington and Galat *et al.* (1981) list 6 species for Pyramid Lake, Nevada (salinity  $5.3 \text{ g l}^{-1}$ ).

Almost all macroinvertebrates in Australian salt lakes are endemic at the rank of species, genus and often family (Bayly and Williams, 1973; Williams, 1981; Geddes *et al.* 1981) and the same largely applies to the water beetles. Australian halophilic species are endemmic, most of the genera involved are different from those known in saline lakes overseas (though they may occur in freshwaters there, eg. most hydrophilid genera), but the families involved are largely similar. The difference at the family level is the penetration of the Sphaeriidae into saline waters in Australia, while at generic level *Enochrus* and *Rhantus* live in salt lakes in both North America (Galat *et al.*, 1981; Rawson and Moore, 1944; Scudder 1969) and Australia.

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# THE IMPACT OF FOREST ROAD CONSTRUCTION ON THE BENTHIC INVERTEBRATE AND FISH FAUNA OF A COASTAL STREAM IN SOUTHERN NEW SOUTH WALES

by

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## ABSTRACT

Benthic invertebrates and freshwater fishes were monitored during and after hardwood logging operations in a coastal forest stream, Mumbulla Creek. Sampling centred around forest roads and a stream crossing responsible for siltation in the creek. Water samples were collected throughout the logging operation by the forestry authority. The results demonstrated changes in the benthic invertebrate communities downstream of logging operations for at least 9 months after associated siltation and elevated turbidity levels first occurred. The abundance of dominant species inhabiting sand and shingle substrates changed more noticeably than those associated with leaf litter. Total drift rates increased as turbidity levels became elevated and species composition observed reflected the relative species densities on substrates. The limitations of these preliminary investigations with respect to data collected are discussed.

## Introduction

The coastal catchments of southern New South Wales include some 317,000 hectares of hardwood forest used for the production of sawlogs and hardwood pulp. The catchments of these forests drain into many freshwater streams and twenty estuaries between Bermagui and the Victorian border.

The effects of various forestry activities on aquatic ecosystems have been widely documented in overseas literature. In Australia, these effects have only been studied in relation to water quality (Cornish, 1976, 1979; Kriek and O'Shaughnessy, 1974) soil (Langford and O'Shaughnessy, 1976) and streamflow and sedimentation (Gilmore, 1971). Morgan and Graynoth (1978) concluded that road building, logging, burning and forest regeneration, and conversion to exotic species were the major forestry activities affecting the ecology of freshwater fish in New Zealand. These particular practices alter streamflow, sediment characteristics, stream morphology, occurrence of log jams and instream debris, dissolved oxygen, light penetration, temperature, plant nutrients, dissolved inorganic and organic materials and introduce chemical pollutants such as herbicides. Cordone and Kelly (1961) discussed the destructive nature of accumulated sediment on stream habitat.

Quantitative studies on the effects of logging activities on freshwater fish are almost entirely based on salmonid species (Gibbons and Salo, 1973). Successful spawning of salmonids and therefore recruitment to the population is adversely affected by siltation and oxygen depletion due to logging (eg. Tebo, 1957).

The species of fish found in streams on the south coast of New South Wales do not have the same spawning habits as salmonids and therefore may not be affected in the same way. However, fish habitat quantity and quality as well as invertbrate production may be adversely affected by excessive siltation. The most apparent cause of siltation reaching streams in logged areas is from roading and stream crossings. This aspect was chosen as the subject of investigation.

### Study Area

Mumbulla State Forest (9,084 hectares) is one of many State Forests on the south coast of N.S.W. where forestry operations are ongoing. This area covers a major part of the catchments of Middle, Wapengo and Murrah Lakes. The study area was centred around Mumbulla Creek, (149° 54'E, 36° 35'S), a permanent freshwater second order tributary of the Murrah River (Fig. 1a). Logging activities such as road construction and timber harvesting were continued in the catchment of Mumbulla Creek throughout 1978. Construction of a causeway over Mumbulla Creek began in January and finished in April, 1978. However, heavy rain caused a washout of the causeway in June that year and reconstruction took place at the end of July.

Sampling sites (Fig. 1b) were selected in relation to this stream crossing to examine if any changes in the structure of the invertebrate and fish faunas were detectable due to disturbance from sediment input. The aquatic habitats of Mumbulla Creek are diverse; rock reefs are common in the upper reaches, interspersed with boulders and shingle bars which persist for its entire length.

The lower reaches have larger pools and coarse sand becomes increasingly common in areas of low velocity. This catchment consists of two geological types; Devonian granite in the upper reaches (sites 1 and 2) and Ordovician sediments in the lower reaches (eg. sites 3 and 5). The average width of Mumbulla Creek at median flows is approximately 6 metres, with some shallow sections spreading to three times this width. The majority of the creek comprises shallow riffle sections averaging approximately 0.2 metres deep, with numerous small pools up to 2.0 metres deep.

At the junction of Mumbulla Creek and the Murrah River, there is a broad floodplain consisting of boulder, shingle and sand deposits, indicating the potential size of the Murrah River in flood. The aquatic habitat in the Murrah River alters to shorter riffle sections interspersed with deeper and larger pools compared to Mumbulla Creek. Coarse grained sand is common in pools with shingle substrates predominating in riffles. Aquatic plant growth is more common in these habitats than in the smaller tributaries.

#### (a) Water Quality and Sediments

##### Materials and Methods

Water samples were collected by the Forestry Commission of N.S.W. from February, 1978, to August, 1979. Samples were taken predominantly on a weekly basis at sites 1, 2 and 3 and analysed for turbidity (N.T.U.), electrical

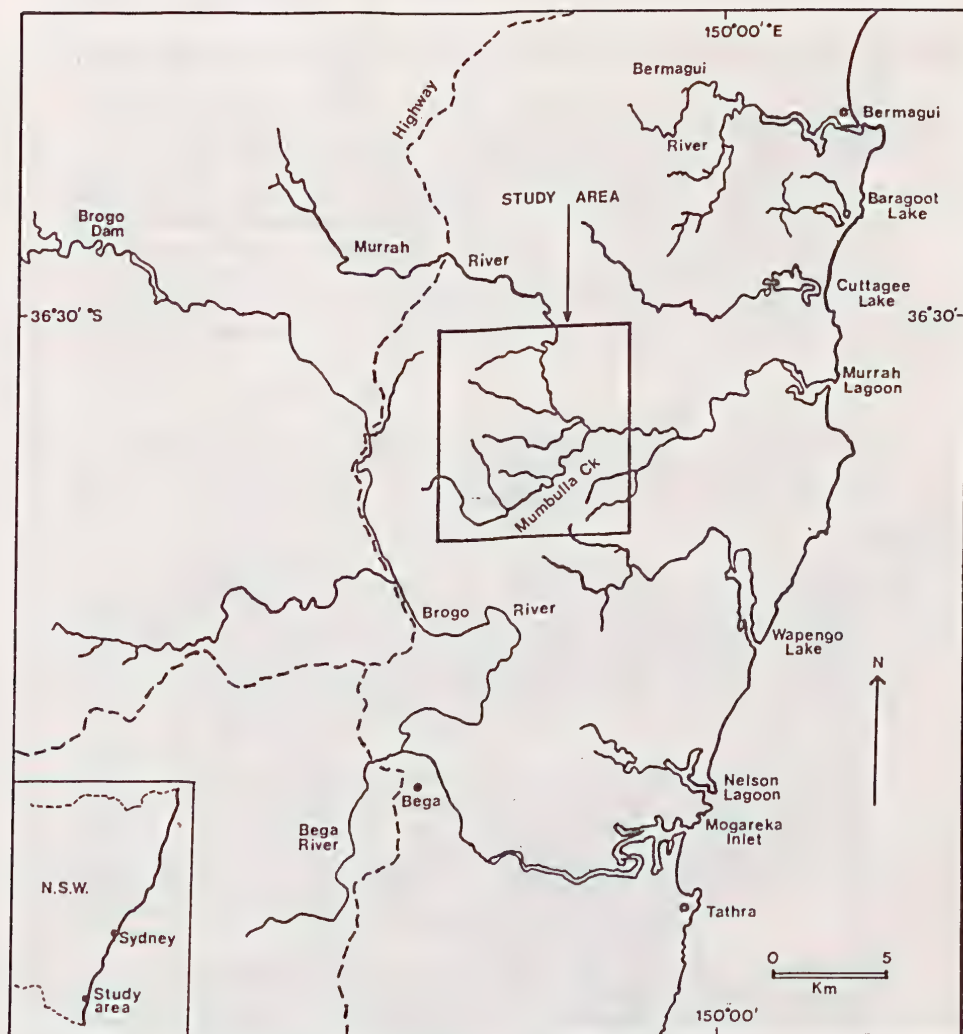


Figure 1a: A map showing the location of the study area.

conductivity ( $\mu\text{S cm}^{-1}$ ) and temperature ( $^{\circ}\text{C}$ ). These results have been published by Cornish (1981) and the raw data set is available in an internal report, Cornish (1979). However, the times of collection were rarely the same day as faunal collections were made and the measurements taken on the date closest to faunal sampling were used in this data analysis.

Ten sediment samples were collected at site 1 and 2 using an inverted 500 ml wide mouth jar in February and November, 1978. In March, 1979, and May 1982, further samples were taken from sites 1, 2 and 3. Total samples were oven-dried and weighed, then wet washed through 200 and 63 micron sieves. Both sediment fractions were re-dried and weighed. A percentage composition by



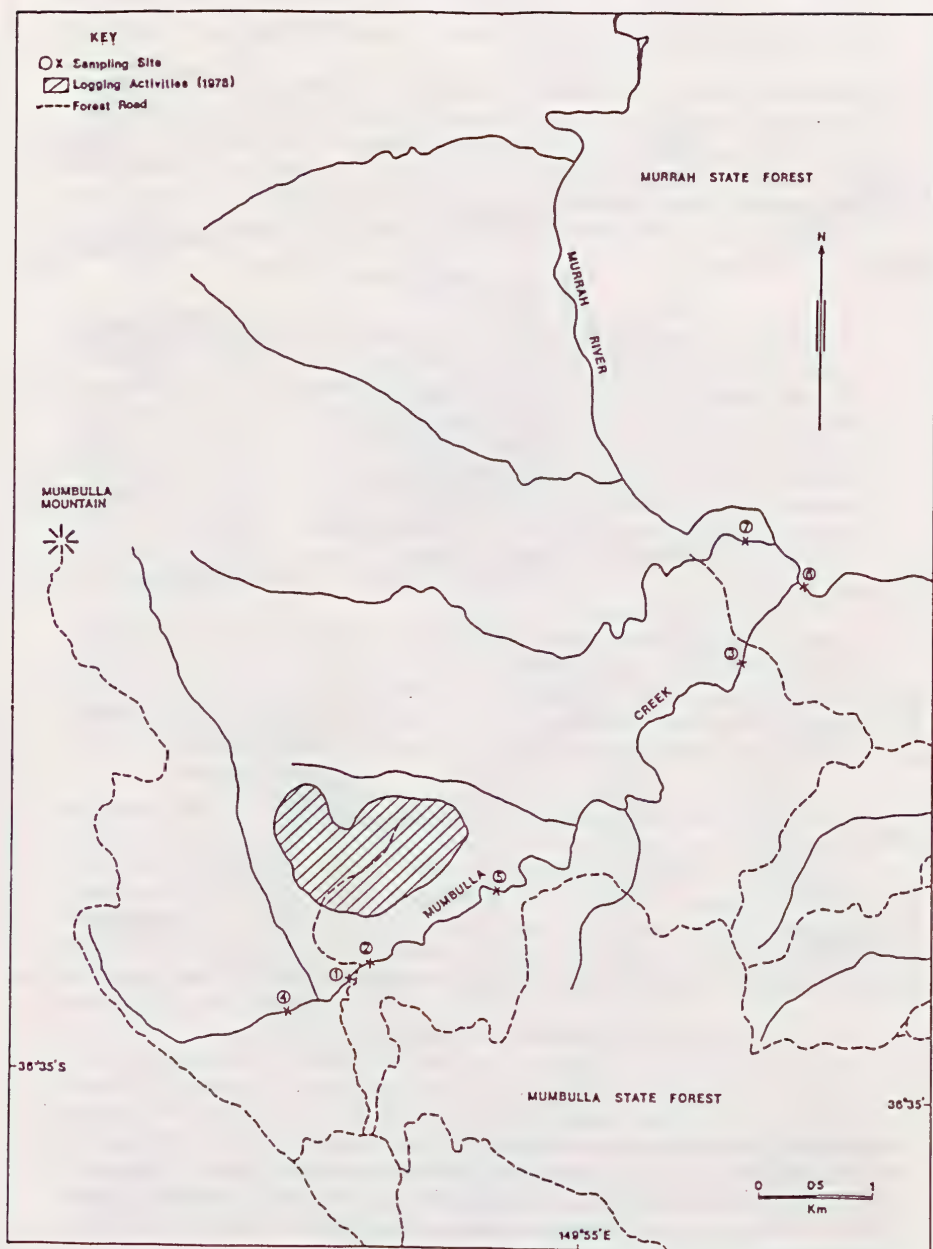


Figure 1b: A map showing the location of the study sites

weight was estimated for each sediment size class. Particle classification was based on Cummins (1962).

## Results

Stream temperatures over the sampling period at sites 1 and 3 are presented in Fig 2. Temperatures at site 3 were slightly lower than at site 1 in winter and slightly higher in summer. Time of sampling may be a main influence on this variation. The mean values for temperatures over the water sampling period (February, 1978, to August, 1979) were 14.6, 14.7 and 14.7°C for sites 1, 2 and 3 respectively. Electrical conductivity was found to be predominantly influenced by geological base rock type in the catchment. The mean values were 82uS cm at site 1, 83uS cm<sup>-1</sup> at site 2 and 109uS cm<sup>-1</sup> at site 3. Cornish (1981) found no correlations between electrical conductivity and stream temperatures with logging activities.

Turbidity levels were influenced by rainfall (Fig. 3) and the stability of the stream crossing. The mean values for turbidity at each site over the study period were 1.3 above the crossing, 30.4 immediately below and 1.5 (N.T.U.) well below the crossing.

The high mean value for site 2 was influenced by six very high readings (maximum 1800 N.T.U.) which corresponded with causeway washout and high flows. These high values were not recorded at site 3 indicating that turbidity values dropped over the 7 kilometres downstream of the causeway. This result indicated that suspended sediment would have been deposited on the stream substrate over this distance or part thereof.

The composition of each sediment sample is presented in Fig. 4. The most noticeable difference between sites was the contribution of mud at site 2 during February – November 1978. This coincided with the construction of the causeway and persisted for at least four months after final construction in July 1978. Samples taken in March 1979 and May 1982 indicated that most of the fine sediment had been flushed from this site.

During June 1978 high rainfall again caused a washout of the causeway, but the data collected did not indicate any elevated turbidities for June. From data presented by Cornish (1979), turbidity levels can drop from 203 to 4.5 (N.T.U.) within 7 days in these streams. In June samples were only collected from 14-29th June, and there was no recorded rise in turbidity to correlate with the causeway washout. This indicates the highly variable nature of water quality in a lotic environment and emphasises the need to monitor levels more frequently in order to document such events properly.

### (b) Benthic Invertebrates

#### Materials and Methods

Benthic invertebrate fauna was collected bimonthly at sites 1, 2 and 3 between March 1978 and March 1979. At each site three different substrates or microhabitats were sampled, ie. one sample from each shingle, sand and leaf litter habitat. Shingle and sand were both sampled using a 0.25 m quadrat (sides 0.35 m deep). The shingle substrates from a riffle section were collected in a 1 mm mesh dip net and thoroughly washed in a bucket of water to remove

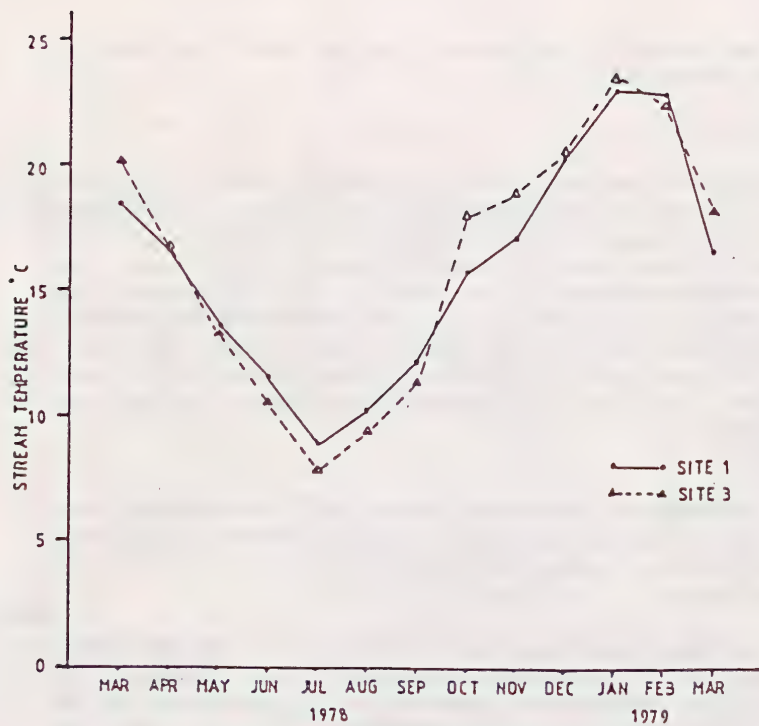


Figure 2: Temperature data for sites 1 and 3

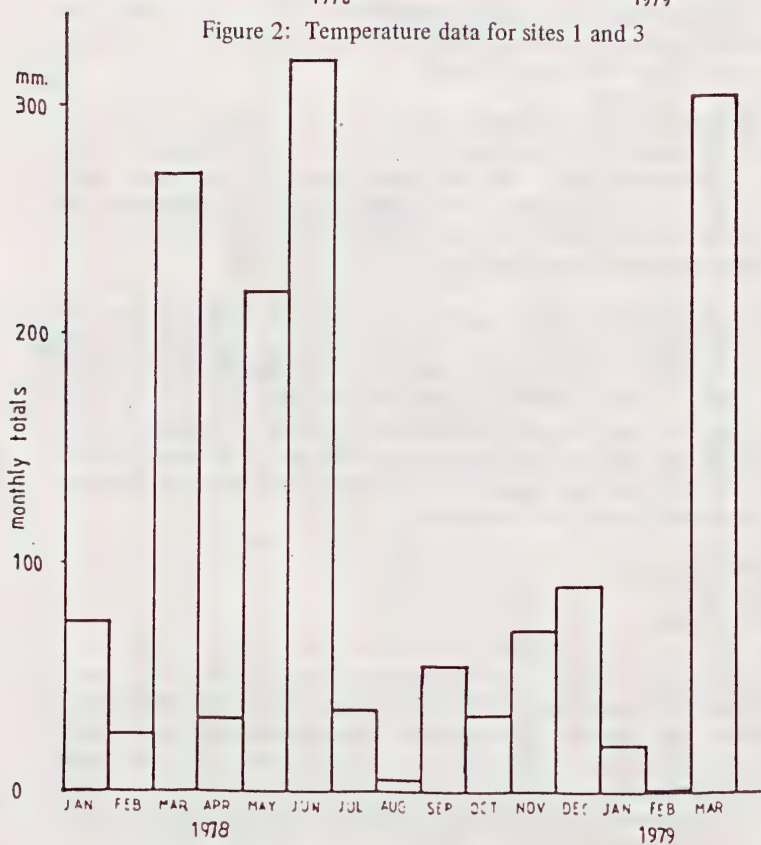


Figure 3: Monthly rainfall at Bega during the study period



adhering organisms. Deposits of sand were sampled by manually disturbing the substrate within the quadrat and the organisms scooped out into a bucket until no further organisms could be detected. Both sand and shingle collections were washed through a 1400 micron Endecott sieve and those organisms remaining in the sieve were collected. Leaf litter was sampled with a dip net and washed in a bucket. The individual pieces of leaf were examined for adhering organisms and the total sample was washed through the same Endecott sieve. The wet weight of the leaf litter sampled was recorded, as area was an inadequate measure of the quantity of substrate sampled due to variations in the depth of the leaf litter. The mean weight of all leaf litter samples was  $75.4 \pm 19.5$  grams.

Drift samples were collected at sites 1 and 3 on each sampling occasion using a Surber sampler with a 1 mm mesh bag. This was set overnight (4 p.m. – 9 a.m. E.S.T.) in a section of flowing water and *in situ* velocity measurements were taken to estimate the volume of water sampled. All specimens collected were preserved in 70% ethyl alcohol.

### Data Analysis

The data were divided into three groups – shingle and sand substrates, leaf litter substrates, and drift samples. This division was based on the different units of measurement employed in sampling the various microhabitats.

The sand/shingle and the leaf litter data sets were analysed by numerical classification and ordination computer programs from the CSIRO TAXON (P2) Library (CSIRO Division of Computing Research). Eleven attributes (species) were masked from the data sets for analysis due to their rare occurrence and their incomplete taxonomic position (asterisks in Appendix I). Clifford and Stephenson (1975) examine the advantages of these techniques in reference to ecological studies of this nature. Substrate, site and time were compared with the generated eigenvector scores using analysis of variance (ANOVA) tests with orthogonal comparisons to establish if these characteristics contributed significantly to the variance of these scores. When significant contributions were calculated, a Newman-Keuls test and a treatment contrast were applied to assess which of the mean scores were different.

Data collected in drift samples were presented as drift rates (No. of organisms per megalitre flow) and correlated with environmental parameters such as temperatures, turbidity and rainfall using Spearman Rank correlation coefficients.

### Results

A total of 95 invertebrate taxa were collected from Mumbulla Creek (Appendix I) of which 71% were identified to generic and 15% to specific level. Appendix II summarises the raw data for abundance and diversity of samples collected on shingle-gravel and leaf litter substrates.

The dendrogram of faunal affinity for the shingle/gravel samples is presented in Fig. 5. The maximum number of groupings (41) was used to give the greatest amount of information on similarity of individuals (samples). Two dominant groups were apparent at a dissimilarity level of 0.74 and these groups represented the two substrate types. The most abundant genera contributing to this dissimilarity based on presence/absence were *Cheumatopsyche*, *Asmicridea*, *Helicopsyche*, *Sclerocyphon* and six of the recorded plecopteran genera which were dominant in the shingle samples. The gravel samples were characterised by

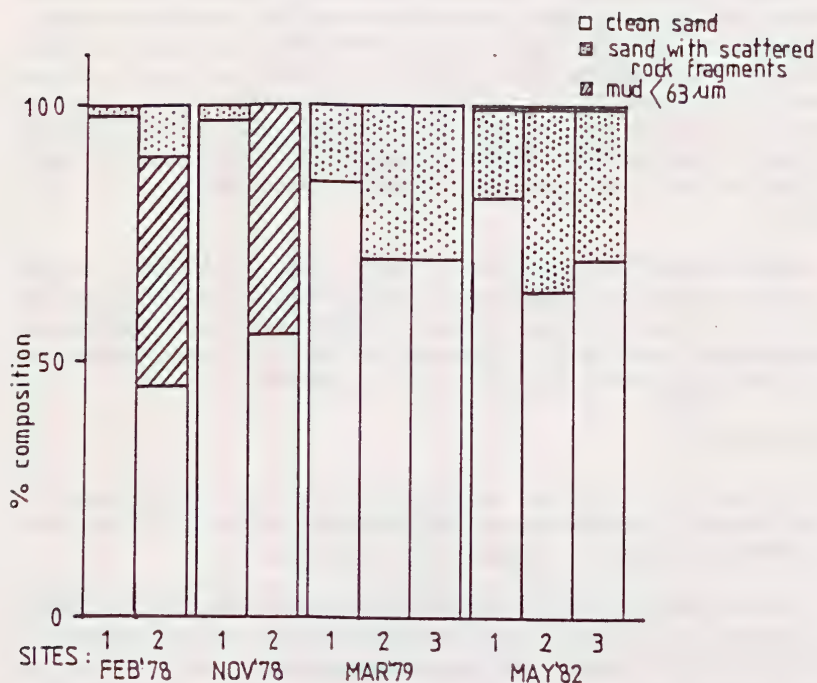


Figure 4: Sediment analysis results, expressed as percentage composition

such taxa as *Aphilorheithrus*, *Berosus* and a libellulid larva. Further groupings were not as apparent as this dividend, although there appeared to be some influence on groupings by sites and times. The later samples from November 1978 to March 1979 tended to be grouped together and those of the period March to September 1978 were also partially grouped. The lack of replicate data sets, use of coarse mesh sieves for collection, known patchiness of benthic invertebrate distributions and the variability of microhabitats have probably precluded the establishment of distinct groups.

A three-way analysis of variance (ANOVA) comparing substrate, site and the two time periods was carried out using the eigenvectors one, two and three, which extracted 47% of the variance in this data set. The ANOVA for eigenvector one (24.3% variance) showed a highly significant difference between substrates ( $F_{1,30} = 255.593$ ,  $P < .001$ ) which was obvious from the dendrogram. There were no two or three way interactions. The same analysis was then performed on eigenvector two (12.8% variance) which gave a significant difference between sites ( $F_{2,30} = 2.615$ ,  $P < .05$ ), and no interactions. A Newman-Keul's test on sites working with treatment totals show site 1 to have a mean of  $-.707$ , site 2 of  $.085$  and site 3  $.621$ . As site 1 varied more than sites 2 and 3, a treatment contrast was used to test the mean score for site 1 against those of sites 2 and 3 combined. This test showed a significant difference between site 1 and the combined mean score of sites 2 and 3 ( $t_{30} = 2.568$ ,  $P < .05$ ).

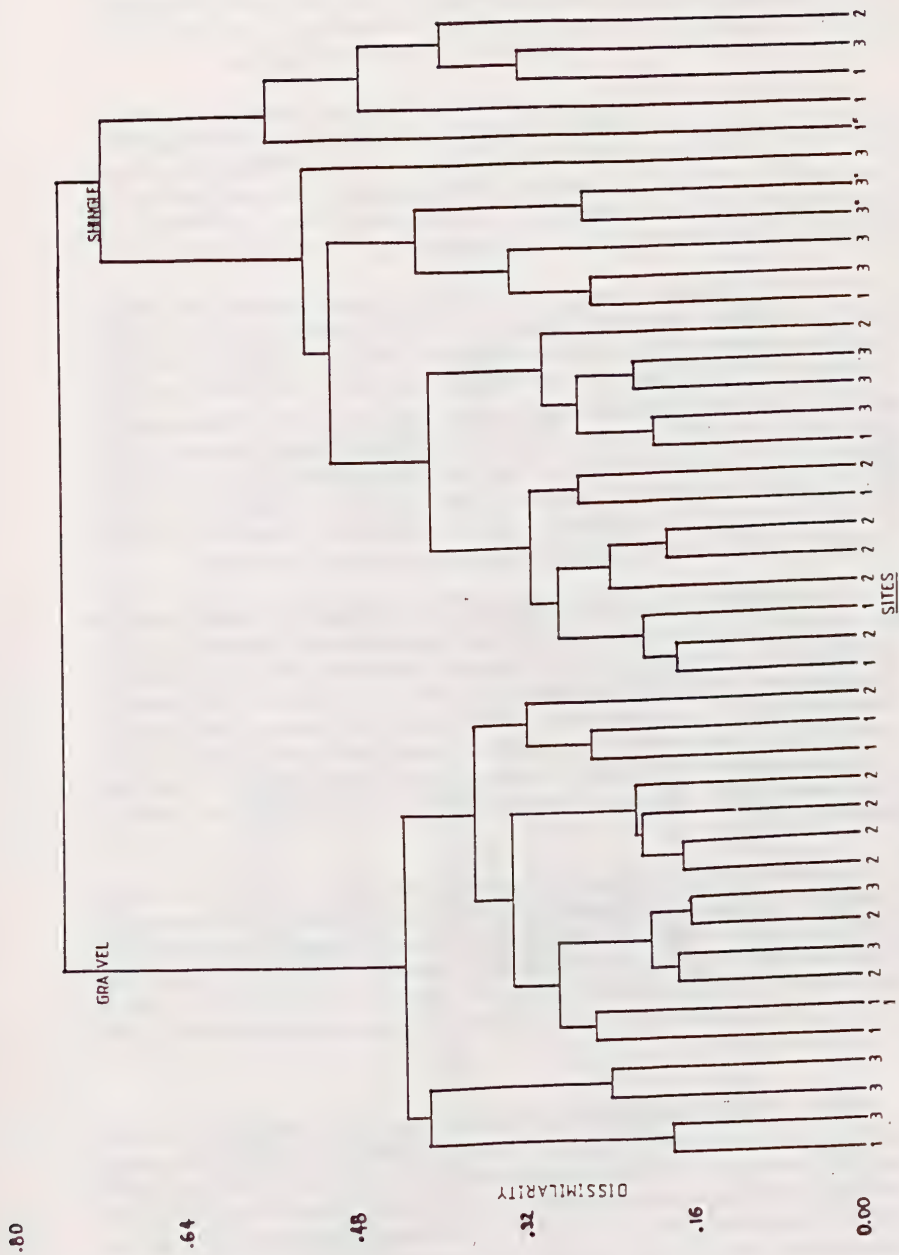


Figure 5: Dendrogram of dissimilarity for gravel and shingle



Eigenvector three, which accounts for 10.4% of the variance was also tested by a three-way ANOVA comparing substrate, site and time. There was a significant difference between times ( $F_{1,30} = 7.544, P < .05$ ), and sites ( $F_{2,30} = 3.316, P < .05$ ). There were no three-way or two-way interactions.

The ordination by principal component analysis was presented to show the degree of clustering for individuals (Fig. 6). As indicated by the Newman-Keul's test, site 1 is seen to be more different than sites 2 and 3. Similar treatments were performed on the leaf litter data. The dendrogram produced from the leaf litter samples did not illustrate any clear groupings (Fig. 7). However, the influence of site and time were again tested against the eigenvector scores.

A two-way analysis of variance was used to compare sites and time against eigenvector scores. The first eigenvector (11.3% variance) was found to be significantly influenced by both site ( $F_{1,15} = 5.7062, P < .05$ ) and time ( $F_{2,15} = 4.0395, P < .05$ ). There were no two-way interactions. Newman-Keul's tests on the mean scores showed similar trends to that found for the shingle/gravel data (site 1 = -.809, site 2 = .09, site 3 = .72). The treatment contrast on the mean scores at site 1 compared to the mean score of site 2 and 3 combined again showed, a significant difference between these sites ( $t_{15} = 2.6937, P < .05$ ). The second eigenvector (10.7% variance) was tested similarly but showed no significant differences between time or site and these scores.

Those species found to be dominant in the leaf litter were *Atalophlebioides* sp., *Ferrisia* sp., *Riekoperla rugosa* and *Anisocentropus bicoloratus*. The abundance of *R. rugosa* dropped noticeably after September, whereas that of *A. bicoloratus* increased dramatically in the January and March (1979) samples. This difference is most likely due to the seasonal life cycles of many benthic invertebrates. The abundance of organisms in samples above the causeway was consistently higher than those from sites 2 and 3 from March – November. The species most apparently reduced were *Atalophlebioides* sp. and *A. bicoloratus*.

The drift rates of organisms per megalitre of flow at sites 1 and 3 were compared with stream temperature, turbidity and monthly rainfall using the Spearman Rank correlation coefficient. There was no significant correlation of drift rates with temperature and rainfall. However, turbidity was found to be significantly correlated with drift rates ( $S = 0.69, t_{10} = 3.02, P < .05$ ). Figure 8 presents the drift rates at sites 1 and 3 and the corresponding turbidities on the closest sampling date.

Table 1 presents the dominant species in each of the drift samples as a percentage occurrence. During increased turbidity in July, the mayfly nymph *Baetis* sp. was the major contributor to the samples at both sites. In March 1979 turbidity was again elevated, and the main species in the drift were the mayfly *Atalophlebioides* sp. and the caddisfly *Anisocentropus bicoloratus* at both sites. *Baetis* sp. was present in very low numbers in March. There appeared to be some seasonality in the dominant species drifting. From May to September, *Baetis* sp. and the stonefly nymph *Riekoperla rugosa* were abundant, whereas their numbers were quite reduced from November to March. Conversely, the numbers of *A. bicoloratus* were high in January and March but very low from May to November. The periods of increase coincided with high densities of each species on their respective preferred substrates.

TABLE 1: Dominant Species in Drift Samples as Percentage Occurrence

| Date            | Site 1                                                      | % Occ.       | Site 3                                                   | %        |
|-----------------|-------------------------------------------------------------|--------------|----------------------------------------------------------|----------|
| May, 1978       | <i>Riekoperla rugosa</i>                                    | 30.1         | <i>Riekoperla rugosa</i>                                 | 26       |
|                 | <i>Atalophlebioides</i> sp.                                 | 19.5         | <i>Baetis</i> sp.                                        | 29       |
| July, 1978      | <i>Baetis</i> sp.                                           | 58.7         | <i>Baetis</i> sp.                                        | 47       |
|                 | <i>Atalophlebioides</i> sp.                                 | 15.4         | <i>Notalina</i> sp.<br><i>Riekoperla rugosa</i>          | 23       |
| September, 1978 | <i>Trinotoperla nivata</i>                                  | 21.3         |                                                          |          |
|                 | <i>Atalophlebioides</i> sp.                                 | 19.5         | <i>Riekoperla rugosa</i>                                 | 56       |
|                 | <i>Baetis</i> sp.                                           | 15.2         |                                                          |          |
|                 | <i>Notalina</i> sp.<br><i>Riekoperla rugosa</i>             | 14.0<br>10.4 |                                                          |          |
| November, 1978  | <i>Atalophlebioides</i> sp.                                 | 46.5         | <i>Dytiscid</i> sp. B                                    | 28       |
|                 | <i>Paratya australiensis</i>                                | 30.6         | <i>Atalophlebioides</i> sp.<br><i>Gomphid nymph</i>      | 11<br>10 |
| January, 1979   | <i>Atalophlebioides</i> sp.<br><i>Paratya australiensis</i> | 30.0<br>26.6 | <i>Anisocentropus bicoloratus</i>                        | 34       |
| March, 1979     | <i>Anisocentropus bicoloratus</i>                           | 25.7         | <i>Atalophlebioides</i> sp.                              | 18       |
|                 | <i>Atalophlebioides</i> sp.<br><i>Sclerocyphon</i> sp.      | 22.5<br>17.9 | <i>Notalina</i> sp.<br><i>Anisocentropus bicoloratus</i> | 13<br>13 |

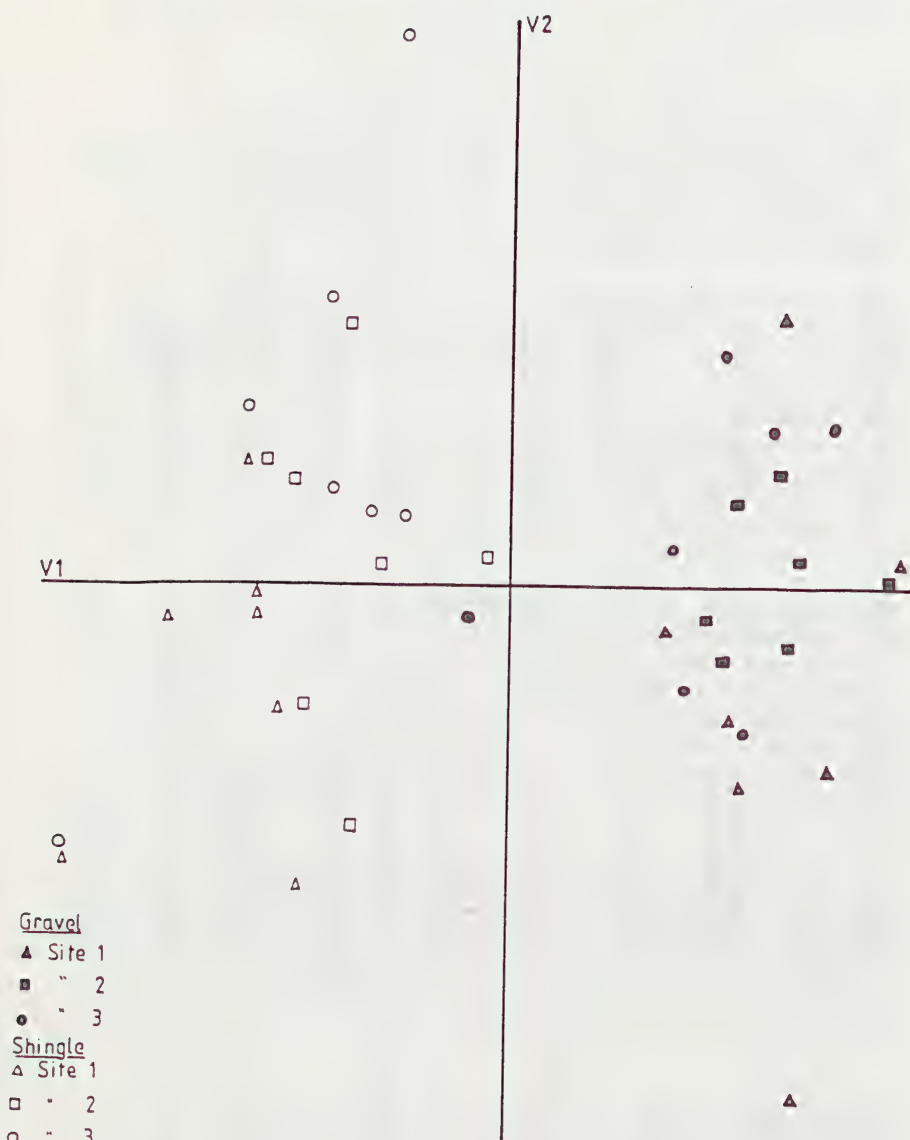


Figure 6: Cluster analysis of vectors 1 & 2 on gravel and shingle



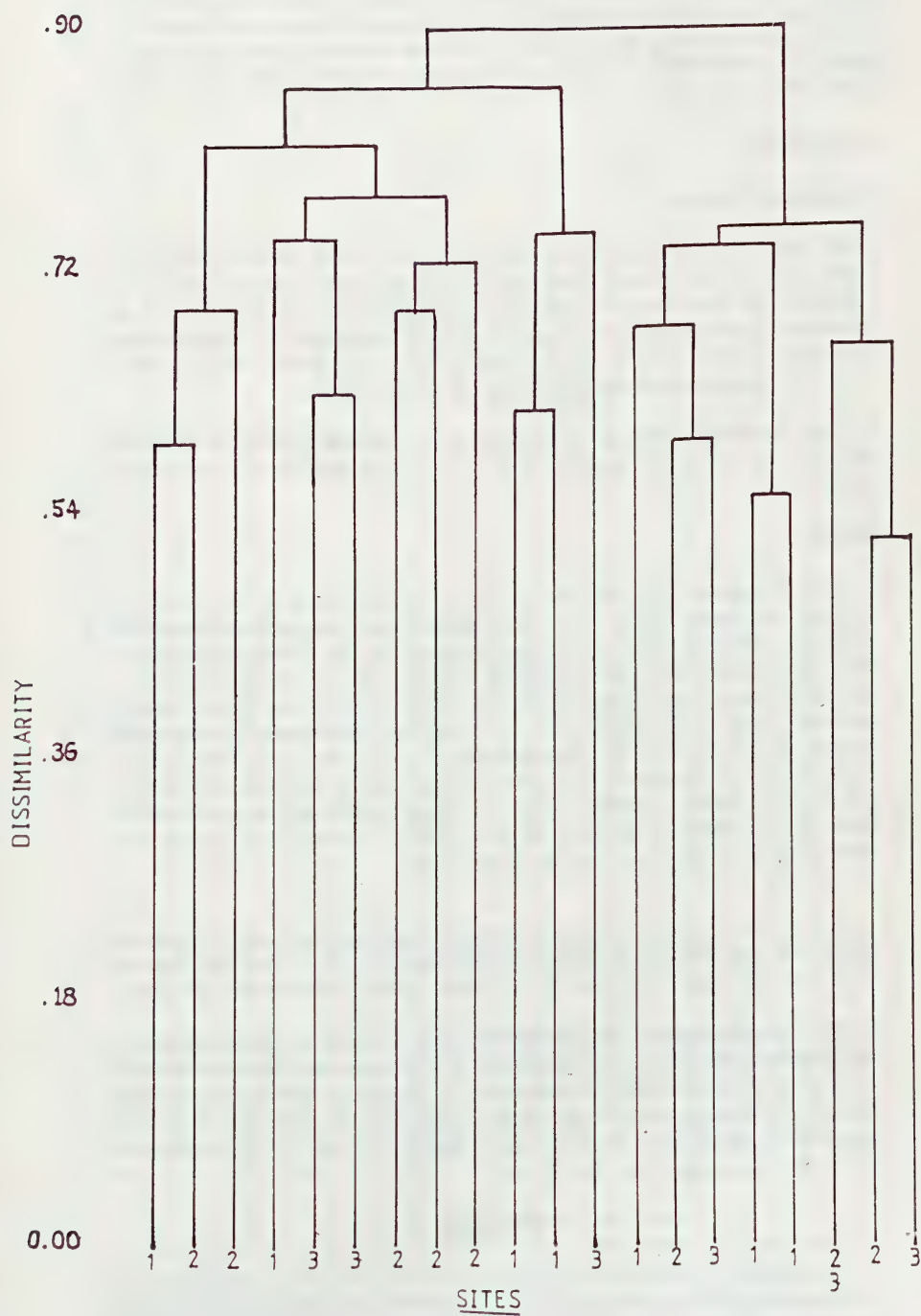


Figure 7: Dendrogram of dissimilarity for leaf litter .

The numbers of *Atalophlebioides* sp. in the drift did not illustrate any seasonal patterns as it was a dominant species all year. However, the abundance of this species was influenced by site. From May to November the numbers at site 1 were consistently higher than those at site 3, whereas in January and March the numbers were not noticeably different. This was consistent with much lower numbers of *Atalophlebioides* sp. on shingle substrates at site 3 compared to site 1 from May to November.

### (c) Fish Fauna

#### Materials and Methods

Fish were collected at four sites (4, 5, 6 and 7) in the Murrah River catchment using a fish poison, Rotenone. Specimens were identified, weighed, measured and their stomach contents were identified. Due to the small size of most species, poisoning proved the most effective sampling tool. Two sampling operations were conducted, site 5 in March, 1979, and sites 4, 6 and 7 in May, 1982. The sampled reach was approximately 30 m at each site.

These data were presented as distribution and abundance for those species in the study area. Stomach contents data were used to identify important food items.

#### Results

Table 2 summarises the distribution and abundance of each species at the site sampled. Mumbulla Creek at sites 5 and 4 had a similar complement of species in 1979 and 1982 respectively, with the exception of the relatively uncommon lamprey and short finned eel. The numbers of jollytail in Mumbulla Creek were noticeably lower than in the Murrah River (site 6) or the unnamed adjacent catchment (site 7). The absence of Cox's gudgeon in the Murrah River was noteworthy, as this was the most abundant species at the other sites. The majority of fish species in the Murrah River differed from those at other sites, which may reflect the difference in habitat. This site was a considerably larger river with fewer shingle substrates and a dominance of sand. Aquatic plant growth was more prolific and the pools were deeper and larger.

Site 7, the unnamed creek, had similar habitat types to those in Mumbulla Creek, but was different in the greater abundance of jollytail and the presence of smelt. This may be related to the undisturbed nature of the catchment.

The stomach contents of those fish collected is shown in Table 3. The jollytail had the most diverse diet of all the fish species examined. The dominant food items were hymenopterans (terrestrial ants) and trichopteran larvae (caddisflies). Ephemeropterans (may flies) nymphs and trichopteran larva were important food items for Cox's gudgeon, and both eel species. Adult dipterans (flies) were dominant in the diet of smelt.

#### Discussion

The sampling intensity used in this study is not sufficient to provide a comprehensive picture of cause and effects. However, the results tend to support some of the trends which have been documented more thoroughly in overseas literature.

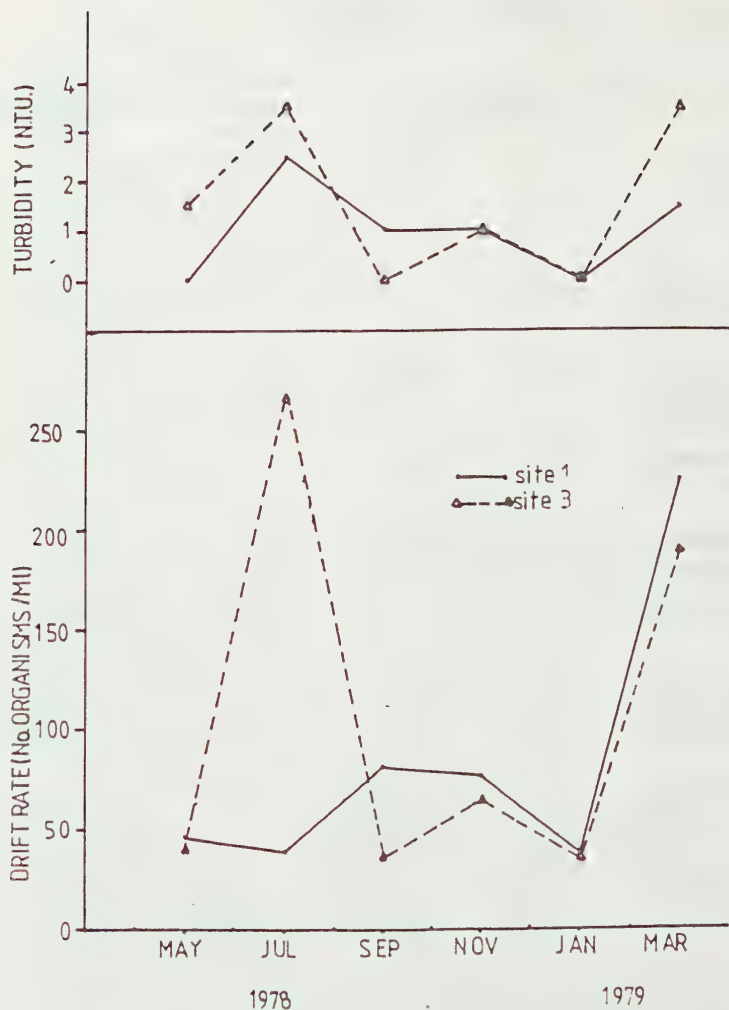


Figure 8: Drift rates and turbidity at sites 1 & 3

The initial construction of the causeway on Mumbulla Creek proved ineffective against high flows caused by heavy rain in March, May and June, 1978. The subsequent improvement in construction of the causeway in late July provided a stable structure which withstood similar high flows in March, 1979. There were few high flows from March, 1979, to May 1982 which may contribute to this longterm stability.

The intensity of water quality sampling was inadequate to illustrate rapid fluctuations in turbidity levels. Continuous monitoring would be recommended if an accurate picture of water quality during flood events is the objective. Similarly, sediment samples should have been taken much more rigorously to indicate the degree of sedimentation and the distance affected downstream. This same inadequacy applies to the water quality data being used as a measure



TABLE 2: Fish Distribution and Abundance in Murrah River Catchment

| DATE<br>SITE                                     | Mumbulla Creek |             | Murrah River | Unnamed Creek |
|--------------------------------------------------|----------------|-------------|--------------|---------------|
|                                                  | 30.3.79<br>4   | 7.5.82<br>5 | 6.5.82<br>6  | 5.5.82<br>7   |
| SPECIES                                          |                |             |              |               |
| <i>Galaxias maculatus</i><br>(Common jollytail)  | 2              | 3           | 31           | 28            |
| <i>Gobiomorphus coxii</i><br>(Cox's gudgeon)     | 98             | 164         | -            | 107           |
| <i>Anguilla reinhardtii</i><br>(Long-finned eel) | 2              | 13          | 6            | 5             |
| <i>Anguilla australis</i><br>(Short-finned eel)  | -              | 3           | -            | 8             |
| <i>Pseudaphrites urvilli</i><br>(Congolli)       | -              | -           | 1            | -             |
| <i>Retropinna semoni</i><br>(Australian Smelt)   | -              | -           | 43           | 2             |
| <i>Philypnodon</i> sp.<br>(Flathead gudgeon)     | -              | -           | 14           | -             |
| <i>Mordicia mordax</i><br>(Lamprey)              | 1              | -           | -            | -             |
| NUMBER OF SPECIES                                | 4              | 4           | 5            | 5             |

of conditions at the time of faunal sampling. The data used for analysis in this report were selected as close to the time of faunal sampling as possible, with not more than 2 days difference. However, it is possible that measurements could change considerably within that time period. Water and faunal samples should be taken concurrently. Apart from these problems, it was apparent that the causeway caused additional siltation and elevated turbidity levels from January to November, 1978.

The classification techniques used to analyse data in this study were found to be preferable to comparisons of diversity since they permitted demonstration of species shift and community response.

The benthic invertebrate communities were highly influenced by substrate type at all sites. Hynes (1970) described substratum as the major factor controlling the occurrence of benthic invertebrates and noted that there is usually a fairly sharp distinction between the types of fauna found on hard and soft

TABLE 3: Stomach Contents – Dominant and Occasional Food Items of Common Fish Species

| Species           | <i>G. maculatus</i> |    |    | <i>G. coxii</i> |    | <i>A. reinhardtii</i> |   |    | <i>A. australis</i> |    | <i>R. semoni</i> |   |
|-------------------|---------------------|----|----|-----------------|----|-----------------------|---|----|---------------------|----|------------------|---|
| Site              | 5                   | 6  | 7  | 5               | 7  | 5                     | 6 | 7  | 5                   | 7  | 6                | 7 |
| Food Item         |                     |    |    |                 |    |                       |   |    |                     |    |                  |   |
| Algae             |                     |    |    |                 |    |                       |   |    |                     |    | +                |   |
| Cladocera         | +                   | +  | +  |                 |    |                       |   |    |                     |    |                  |   |
| Ostracoda         |                     |    |    | +               |    |                       |   |    |                     |    |                  |   |
| Atyidae           |                     | +  | +  |                 | +  |                       |   |    |                     |    |                  |   |
| Bivalvia          |                     | +  |    |                 |    |                       |   |    |                     |    |                  |   |
| Gastropoda        |                     | +  |    | +               | +  |                       |   |    |                     |    |                  |   |
| Arachnida         |                     |    | +  |                 |    |                       |   |    |                     |    |                  |   |
| Nematoda          |                     |    | +  |                 |    |                       |   |    |                     |    |                  |   |
| Oligochaeta       | +                   | +  |    |                 |    |                       |   |    |                     |    |                  |   |
| Hymenoptera       | ++                  |    | +  |                 |    |                       |   |    |                     |    |                  |   |
| Orthoptera        |                     |    | +  |                 |    | +                     |   |    |                     |    |                  |   |
| Ephemeroptera     | +                   |    | +  | +               | ++ | ++                    | + | ++ | +                   | ++ |                  | + |
| Trichoptera       | +                   | ++ | +  | ++              | ++ |                       | + |    | +                   | ++ | +                | + |
| Plecoptera        |                     |    |    |                 | +  |                       |   |    |                     |    |                  |   |
| Odonata           | +                   |    |    | +               |    |                       |   |    |                     |    |                  |   |
| Coleoptera adults | +                   | +  | +  | +               |    |                       |   |    | +                   |    | +                |   |
| larva             | +                   | +  | +  | +               | +  |                       | + |    |                     | +  |                  |   |
| Hemiptera         | +                   | +  | +  |                 |    |                       |   |    |                     |    |                  |   |
| Diptera larvae    |                     |    | +  | ++              | +  |                       |   |    |                     |    |                  |   |
| pupae             |                     |    | +  |                 |    |                       |   |    |                     |    | +                |   |
| adults            | +                   | +  | +  |                 |    |                       |   |    |                     |    | ++               | + |
| Fish              |                     |    |    |                 |    | +                     |   |    | +                   |    |                  |   |
| *Sub-sample No.   | 4                   | 20 | 20 | 20              | 20 | 5                     | 6 | 1  | 3                   | 4  | 9                | 2 |

\* Sample No. does not include empty stomachs.

++ Occurs in 50% or more of all stomachs.

+ Occurs in less than 50% of all stomachs.

stream beds. Those species found to be most abundant on shingle, e.g. *Cheumatopsyche* and *Sclerophon*, are recognised as possessing morphological adaptations to fast flowing water; similarly, those dominant species in the sand fauna are adapted to slower depositional habitats.

Groupings of samples beyond substrate type were not considered sufficiently conclusive due to the sample sizes. Cordone and Kelly (1961) have reviewed the sampling problems arising from the use of a small number of samples to assess the effects of sediment on stream life. They concluded that the major factor contributing to the confusion amongst groups is probably the lack of random distribution of organisms, and therefore recommended a large number of replicate samples.

The ANOVA tests carried out on the eigenvector scores indicated some further groupings of samples not clearly evident from the dendrogram plot. The shingle/sand communities at site 1 above the causeway were significantly different from downstream sites 2 and 3 combined. The conditions at the beginning of the survey and the later samples were also significantly different.

The deposition of silt or sand on stony substrates have been shown to reduce the abundance and emergence of mayflies, caddie-flies and stoneflies, even when deposits remain for only part of the year (Hynes, 1970). Although the data collected here are too limited to show quantitative changes in key species, there appears to be sufficient change in the community structure to distinguish between site 1 and the two downstream sites as well as to indicate differences in the community structure over time, from March – September to November – March. This time difference appears to be primarily due to a greater rate of sedimentation in the initial months of the survey.

The leaf litter communities were not as strongly indicative of changes as those of other substrates. However, the same general pattern emerged as was evident for the shingle and gravel substrates. Organisms inhabiting leaf litter commonly feed on the detrital material and many live within dead wood. The dominant species found inhabiting leaf litter substrates were *Anisocentropus bicoloratus*, *Ferrisia* sp. (a gastropod), *Atalophlebioides* sp. (a mayfly nymph) and *Riekoperla rugosa* (a stonefly nymph). Merritt and Cumming (1978) describes the trophic relationships of the family groups that these species fall into as either general collectors (scrapers) or shredders (detritivores).

Leaf litter was not a good indicator of community response to siltation as the deposits can vary in the degree of the decomposition and this in turn probably effects the availability of food for scrapers (e.g. *Atalophlebioides*) and the quantity of decaying timber which is reported to attract some specialised species (Hynes, 1970).

High turbidity levels have been shown to increase drift rates of benthic invertebrates (White 1976, Pearson and Franklin 1968). Although turbidity values were only taken within 2 days of faunal samples, a significant correlation was found between drift rates and turbidity levels. The species most obviously affected by elevated turbidities were *Baetis* sp. and *Anisocentropus bicoloratus*. Pearson and Franklin (1968) in an American study showed that *Baetis* sp. was found to increase significantly in the drift with increases in turbidity from 25 – 700 p.p.m. The species they studied is likely to be different from that found in Mumbulla Creek, but the response to increase in turbidity appears to be similar. The increased number of *Baetis* and *A. bicoloratus* in different seasons coincided

with increased densities of these species on their preferred substrates, indicating seasonal variations in abundance. Pearson and Franklin (1968) found a high positive correlation between drift rates over 24 hours and bottom densities for both *Baetis* and simuliid larvae.

In this study, *Atalophlebioides* sp. did not show this seasonal variation in abundance, being dominant in drift samples throughout the year. However, there was a reduction in numbers drifting and on substrates at site 3 from May to November. This species appears to have been reduced in abundance at site 3 during the early part of the survey, and this may be related to the immediate effects of sedimentation. Therefore the component species in the drift appear to be affected by the species density in the substrates and to varying degrees by turbidity levels. Total drift rates were increased with increased turbidity and this in turn may have a significant effect on the bottom fauna if high turbidity levels continue for an extended period.

A total of five species of fish were recorded in Mumbulla Creek. The most abundant species was *Gobiomorphus coxii*. The distribution and abundance of *G. coxii*, *Anguilla australis* and *Anguilla reinhardti* did not appear to be affected by the stream crossing though numbers of the latter two were very low. In a study on the effects of different logging practices on freshwater fauna, Graynoth (1979) noted that the species *Gobiomorphus breviceps*, *Anguilla diffeinbachii* and *A. australis* were apparently unaffected by heavy sedimentation and increased suspended soils. Although two of the species collected in Mumbulla Creek are different, their habitat requirements are similar and the local species also appear tolerant of these conditions.

There were noticeably lower numbers of *Galaxias maculatus* in Mumbulla Creek compared to the very similar habitat of the adjacent catchment. Again Graynoth (1979) found that the abundance of *Galaxias divergens* were greatly reduced in a stream where clearfell logging had increased sedimentation and suspended solids. He found these fish had increased growth rates and fecundity, and a less diverse and different diet from those in less disturbed streams in the same area. Morgan and Graynoth (1978) have described the aspects of the ecology of *G. maculatus* and *G. divergens* which may be affected by sedimentation. The adults seek cover in the interstices of the stream substrate which may be spatially reduced by sedimentation and this in turn increases the competition and predatory pressure on the species. Adults also lay their eggs among grasses and other stream bank vegetation which can be smothered by sediments. Their diets were carnivorous and varied as food preferences depend on the foods available in a particular area.

The absence of *Retropinna semoni* in Mumbulla Creek may not be influenced by sedimentation, as the numbers in the undisturbed catchment were also low. This species tends to prefer slow-flowing waters and pools (McDowall, 1980), which are more common in the Murrumbidgee River. The frequency of fish sampling in this study is not sufficient to document any decreases in populations. However, the low numbers of *G. maculatus* in the affected stream are noteworthy.

### Conclusion

The results of this study are limited due to the scale of sampling but do indicate some of the impacts of sedimentation and turbidity caused by poor roading and causeway construction which may be associated with forestry activities.



Sedimentation and elevated turbidity levels changed the benthic invertebrate community downstream for at least 7 kilometres over a period of approximately 9 months after the sediment influx. Increased turbidity levels were found to affect the drift rates of some species. The abundance of *Galaxias maculatus* was found to be lower in Mumbulla Creek compared to other sites sampled.

### Acknowledgements

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# APPENDIX I      BENTHIC INVERTEBRATE SPECIES LIST

|              |                 |                                        |
|--------------|-----------------|----------------------------------------|
| CRUSTACEA    | — Decapoda      | <i>Euastacus claytoni</i>              |
|              | — Atyidae       | <i>Atya striolata</i>                  |
|              |                 | <i>Paratya australiensis</i>           |
| ARACHNIDA    | — Acarina       | <i>Hydracarina</i>                     |
|              | — Araneae       | <i>Dolomedes</i> Sp.                   |
| GASTROPODA   | — Ancyliidae    | <i>Ferrissa</i> Sp.                    |
|              | — Planorbidae   | <i>Isodirella</i> Sp.                  |
| OLIGOCHAETA  | — Naididae      | Species A.                             |
| NEMATOMORPHA | — Gordioidae    | <i>Parachordodes</i> Sp.               |
| INSECTA      | — Ephemeroptera | <i>Atalophlebioides</i> Sp.            |
|              |                 | <i>Atalophlebia</i> Sp.                |
|              |                 | <i>Atalonella</i> Sp.                  |
|              |                 | <i>Jappa</i> Sp. A.                    |
|              |                 | <i>Jappa</i> Sp. B.                    |
|              |                 | <i>Tasmanocoenis</i> Sp.               |
|              |                 | <i>Baetis</i> Sp. A.                   |
|              |                 | <i>Baetis</i> Sp. B.                   |
|              |                 | <i>Centroptilum</i> Sp.                |
|              |                 | <i>Tasmanophlebia</i> Sp.              |
|              |                 | <i>Mirawara</i> Sp.                    |
|              |                 | <i>Apsilochorema</i> Sp.               |
|              |                 | <i>Ulmerochorema</i> Sp.               |
|              |                 | <i>Taschorema</i> Sp.                  |
|              |                 | <i>Agapetus</i> Sp.                    |
|              |                 | <i>Orphninostrichia</i> Sp.            |
|              |                 | <i>Tricoglene</i> Sp.                  |
|              |                 | <i>Hellyethira simplex</i>             |
|              |                 | <i>Orthotrichia</i> Sp.                |
|              |                 | <i>Oxyethira</i> Sp.                   |
|              |                 | * <i>Hydrobiosella</i> Sp.?            |
|              |                 | * <i>Ecnomina</i> Sp?                  |
|              |                 | <i>Cheumatopsych</i> Sp.               |
|              |                 | <i>Asmicridea edwardsi</i>             |
|              |                 | * <i>Diplectrona</i> Sp.?              |
|              |                 | <i>Tasiagma</i> Sp.                    |
|              |                 | <i>Helicopsyche</i> Sp.                |
|              |                 | * <i>Lingora</i> Sp.?                  |
|              |                 | * <i>Coenoria</i> Sp.?                 |
|              |                 | * <i>Marilia</i> Sp.?                  |
|              |                 | <i>Anisocentropous bicoloratus</i>     |
|              |                 | <i>Kosrheithrus</i> Sp.                |
|              |                 | <i>Aphilorheithrus</i> Sp.             |
|              |                 | * <i>Larva</i> Sp. A.                  |
|              |                 | <i>Notalina</i> Sp.                    |
|              |                 | <i>Oecetis</i> Sp.                     |
|              |                 | <i>Triplectides</i> Sp.                |
|              |                 | <i>Allocella</i> Sp.                   |
|              |                 | * <i>Polycentropodid</i> Larva. Sp. B. |
|              |                 | * <i>Larva</i> Sp. C.                  |
|              |                 | * <i>Caloca</i> Sp.?                   |
|              |                 | * <i>Caenota</i> Sp.?                  |

|             |                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Plecoptera  | <i>Stenoperla australis</i><br><i>Trinotoperla nivata</i><br><i>Leptoperla nevoissi</i><br><i>Leptoperla</i> Sp.<br><i>Riekoperla rugosa</i><br><i>Dinotoperla serricauda</i><br><i>Illiesoperla australis</i><br><i>Austrocercella</i> Sp.                                                                                                                                                                       |
| Odonata     | <i>Diphlebia</i> Sp.<br><i>Argiolestes</i> Sp.<br><i>Gomphid nymph</i> Sp.<br><i>Aeshnid nymph</i> Sp.<br><i>Libellulid nymph</i> Sp.                                                                                                                                                                                                                                                                             |
| Coleoptera  | <i>Dytiscid</i> adult Sp. A.<br><i>Dytiscid</i> larva Sp. B.<br><i>Carabid</i> larva Sp.<br><i>Berosus</i> Sp.<br><i>Hydrophilid</i> adult Sp. A.<br><i>Hydrophilid</i> adult Sp. B.<br><i>Simsonia</i> Sp.<br><i>Hydrochus</i> Sp.<br><i>Haliphus</i> Sp.<br><i>Heleodid</i> larve Sp.<br><i>Sclerocyphon</i> Sp.<br><i>Macrogyrus</i> Sp.<br><i>Ptilidactylid</i> larva Sp.<br><i>Austrolimnius waterhousei</i> |
| Hemiptera   | <i>Macronecta gracilia</i><br><i>Enithares</i> Sp.<br><i>Tenagogerris</i> Sp.<br><i>Nerthra</i> Sp.                                                                                                                                                                                                                                                                                                               |
| Diptera     | <i>Chironomid</i> larva Sp. A.<br><i>Chironomid</i> larve Sp. B.<br><i>Chironomid</i> pupa Sp. C.<br><i>Ceratopogonid</i> larva Sp.<br><i>Culicid</i> larva Sp. A.<br><i>Culicid</i> pupa Sp.<br><i>Similid</i> larva Sp.<br><i>Tipulid</i> larva Sp.<br><i>Tabanid</i> larva Sp.<br><i>Emphid</i> larva Sp.<br>Unid. Larva Sp.                                                                                   |
| Megaloptera | <i>Austrosialis</i> Sp.<br><i>Archichauliodes</i> Sp.                                                                                                                                                                                                                                                                                                                                                             |

\* Species masked out for numerical classification programme.

## APPENDIX II

### RAW DATA – AS TOTAL ABUNDANCE AND NO. OF SPECIES PER SAMPLE

| SUBSTRATE                               | SITE |          |     |          |     |         |
|-----------------------------------------|------|----------|-----|----------|-----|---------|
|                                         | 1    |          | 2   |          | 3   |         |
|                                         | No.  | Spp. No. | No. | Spp. No. | No. | Spp No. |
| Gravel<br>(0.25 m <sup>2</sup> )        | 18   | 9        | 32  | 10       | 14  | 8       |
|                                         | 11   | 7        | 6   | 5        | 17  | 4       |
|                                         | 13   | 7        | 32  | 6        | 23  | 11      |
|                                         | 6    | 6        | 12  | 6        | 57  | 11      |
|                                         | 25   | 10       | 10  | 6        | 63  | 8       |
|                                         | 60   | 15       | 14  | 8        | 42  | 10      |
|                                         | 28   | 10       | 13  | 6        | 16  | 5       |
|                                         |      |          |     |          |     |         |
| Shingle<br>(0.25 m <sup>2</sup> )       | 64   | 11       | 102 | 7        | 29  | 10      |
|                                         | 126  | 9        | 57  | 8        | 35  | 11      |
|                                         | 57   | 12       | 78  | 6        | 29  | 10      |
|                                         | 100  | 7        | 60  | 10       | 47  | 12      |
|                                         | 103  | 13       | 42  | 11       | 90  | 16      |
|                                         | 231  | 17       | 65  | 11       | 91  | 16      |
|                                         | 99   | 17       | 67  | 12       | 33  | 8       |
|                                         |      |          |     |          |     |         |
| Leaf Litter<br>(per 75.4<br>+ 19.5 gms) | 32   | 10       | 22  | 8        | 7   | 5       |
|                                         | 38   | 5        | 6   | 4        | 8   | 5       |
|                                         | 35   | 5        | 27  | 4        | 15  | 6       |
|                                         | 44   | 8        | 17  | 5        | 20  | 6       |
|                                         | 75   | 13       | 25  | 9        | 29  | 8       |
|                                         | 107  | 10       | 101 | 14       | 139 | 9       |
|                                         | 82   | 10       | 75  | 10       | 43  | 6       |
|                                         |      |          |     |          |     |         |





## THE AQUATIC HABITAT AND FAUNA OF EAST GIPPSLAND, VICTORIA

by

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### Abstract

Catchments in the little studied and comparatively pristine area from the Snowy River east to Cape Howe are faced with potentially major changes in land use, especially from intensive logging. Many perennial streams occur in the region, from first to sixth order, and range from spring fed streams across mainly organic substrata, to sandy coastal streams, to torrential streams across bedrock and boulders with spectacular gorges and waterfalls. Boulders, cobbles and pebbles are the most common bed type. Standing waters include montane swamps, coastal swamps and lakes of the floodplains, perched sand-dune lakes and extensive estuaries.

Little is known about the aquatic invertebrates of the region. What is known suggests that the invertebrate fauna is very diverse, with four main components — widespread species of temperate Australia; species endemic to the area; mainly east coast forms reaching their southern limit in East Gippsland; and mainly inland species penetrating along some drier river valleys.

While much still remains to be learned of fishes of East Gippsland, basic distribution patterns are known. Fifty-three species have been recorded from freshwaters and estuaries of East Gippsland, 24 being 'freshwater' forms, out of a total of 36 in coastal drainages in southern New South Wales and Victoria. Six species classed as either vulnerable or restricted/rare in Victoria are found in East Gippsland waters. Few introduced species occur, and their influence is small.

The impact of erosion sediment and log-jams upon fish and invertebrates is discussed. Aspects of past and present logging procedures which are seen as likely to have an adverse effect upon aquatic biota are — absence of buffer zones on headwater and tributary channels; inadequate buffer strips along streams; unsatisfactory construction and maintenance of roads; and possibly logging of excessively steep slopes. The need for detailed studies of stream beds and the aquatic fauna in logged and unlogged areas is stressed.

### The Habitats

The aquatic habitats of Gippsland from the Snowy River east to Cape Howe (East Gippsland, Fig. 1) have a value disproportionate to the small area they cover. They are extremely varied, little altered by human activities and little known, physically, chemically and biologically. Their relatively pristine condition makes them important as scientific reference areas against which the other aquatic habitats in south-eastern Australia can be compared. There is an

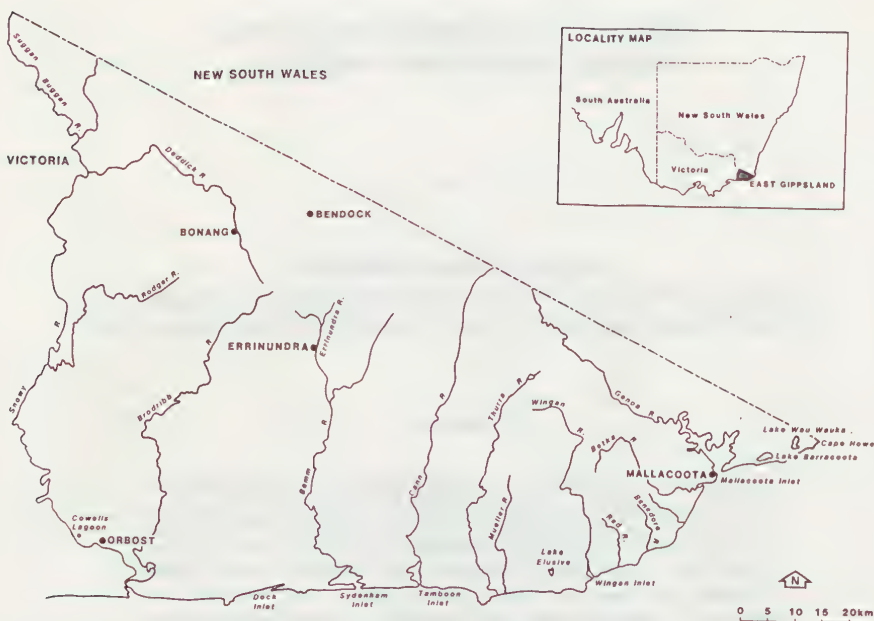


Figure 1: East Gippsland showing rivers and place names referred to in the text.

urgent need for detailed studies of their physical condition and biota, because previously untouched forested catchments are now faced with intensive logging operations. The following are brief summaries of our present knowledge of the habitats and the invertebrates and fishes that occur in them.

Physiographically and geographically, East Gippsland is a continuation of south-eastern New South Wales. The bedrock consists mainly of Ordovician sediments intruded by several major Silurian or Devonian granitic bodies. Early Devonian volcanic complexes occur in the west (eg. part of the catchment of the Rodger River, a tributary of the Snowy), and non-marine sediments from the valleys of several present day streams (eg. sections of the Cann and Thurra Rivers). Extensive sands and gravels of principally non-marine origin occur along the southern part of the highlands, and well-developed dune systems of a late Quaternary age are present along the coast (Talent 1969). McRae-Williams et al. (1981) showed that many of the coastal wetlands, and physical structures related to rivers, have high geological and geomorphological significance, often at state and national level.

In East Gippsland there are four main physiographical units (Fig. 2). The elevated tablelands including the Errinundra Plateau are an extension of the Monaro Tablelands of New South Wales, and the gently undulating terrain consists of generally broad valleys and moderate divides. The Monaro Tablelands have been almost totally cleared of forest whereas much of the East Gippsland

plateau area remains undisturbed. The unit covering the largest area of East Gippsland consists of more deeply incised valleys with occasional mountainous areas standing above the ridges. The topography is of more steeply sloping ridges and a complex pattern of dissection. The plains unit is a complex of coastal tablelands, low ranges, swamps and generally weakly incised valleys. The coastal dune unit consists of sands and associated swamp and lacustrine deposits with dunes running parallel to the prevailing winds (Talent 1969).

Climatically, East Gippsland differs in many respects from the remainder of Victoria. Rainfall is affected by both monsoonal influences from the north and by cyclonic disturbances from the east. Most of its rainfall comes from atmospheric depressions centered off the east coast of Australia and there are no seasonal trends in their occurrence (Karelsky 1965). In montane areas occasional snowfalls occur in winter. Rainfall is plentiful and evenly distributed throughout the year; droughts sometimes occur but seldom last longer than a few months (Land Conservation Council (L.C.C.) 1974). Consequently, the many perennial rivers draining the highlands maintain relatively consistent flows throughout the year.

The Environment Protection Authority (EPA 1983) provide hydrological data for 15 of the larger rivers in East Gippsland, and physical and chemical information for two freshwater sites on each of the Snowy, Brodribb, Bemm, Cann and Genoa Rivers. The Snowy, the largest East Gippsland River, is nearly 500 km long, has an annual average discharge of 1820 G1 and its catchment (over 13,000 km<sup>2</sup>) extends well into New South Wales. Other important waterways, including the Bemm, Cann and Genoa Rivers are smaller in catchment and discharge by about a factor of ten. Streams draining the coastal foothills and including the Mueller, Red and Wingan Rivers, are smaller again by at least a factor of ten.



Figure 2: Main physiographical units of East Gippsland. (after L.C.C. 1974)



There are many headwater tributaries, encompassing seasonal streams rising in the drier woodlands of coastal foothills and higher mountains, as well as perennial creeks fed by springs, basins and swamps of such high rainfall areas as the Errinundra Plateau. Ladd (1979, a and b) described the vegetation of swampy areas on the north flowing Delegate River and on the headwaters of the south flowing Errinundra River. The swamps are surrounded by mainly snow-gum (*Eucalyptus pauciflora*/*E. stelluata*) communities on the Delegate River and by shinning gum (*E. nitens*) and rainforest species on the Errinundra. Sphagnum bog occurs in both areas, but considerable differences occur in the species composition of aquatic and semi aquatic plant communities.

Streams of fourth order or less flow over a variety of bed types, including swampy organic material, but boulders, cobbles and pebbles predominate. Macmillian (1984) identified nineteen fully forested third order catchments of the East Gippsland plateau region, of which eleven were accorded high conservation status. Streams draining the Errinundra Plateau are very diverse, and have some spectacular sections of cascades and waterfalls. Blyth (1984) provided a brief physical description of some of these streams, several of which fall 700 m in elevation over a distance of about 4 km, and have a rapid gradient in many physical and biological factors. Considerable habitat diversity, high landscape, scientific and educational values, and (in some cases) pristine state, give streams such as the east branch of the Errinundra River very high value for conservation, and as reference catchments (Blyth 1984).

On the coastal plains there are extensive freshwater swamps, limited areas of salt marsh (Barson and Calder 1981), and most of the major rivers have large estuaries. Coastal sand-dunes formed across the mouths of several rivers have acted as barriers which have been responsible for the development of several coastal 'lakes,' e.g. Sydenham Inlet on the Bemm River, Tamboon Inlet on the Cann River and Mallacoota Inlet on the Genoa River (Reinson 1976). Most are relatively shallow; the deepest, Tamboon Inlet, having an average depth of about 10 m (B.R. Tunbridge, Fisheries and Wildlife Division, Victoria, personal communication, 1981). During periods of low flow the smaller estuaries, in particular, may be closed to the sea.

Large east coast depressions can cause substantial amounts of rainfall in short periods of time. The frequency of 24 hour falls higher than 75 mm is greater in East Gippsland than in other parts of Victoria (Linforth 1969). This rainfall frequently causes rapid rises in coastal rivers such as the Bemm and the Cann. Heavy rainfall further inland is less frequent but the Snowy floods once or twice a year when heavy rain falls over the whole catchment, and rapid rises of between 75 mm and 575 mm can occur in 24 hours.

The catchments of the larger rivers are often relatively narrow and steep sided, sometimes forming spectacular gorges. Much of the Snowy River Gorge is considered to be of national significance for geomorphological and landscape features, while the Genoa River Gorge has paleontological features of international importance (McRae-Williams et al. 1981).

The types of river bed vary; the Snowy, Betka and Mueller Rivers flow over bedrock, cobbles and pebbles for much of their length, whereas the Cann, Thurra and Bemm Rivers flow over predominately sandy beds. An analysis of the structural complexity of stream substrata in middle and lower freshwater reaches of the Snowy, Brodripp, Bemm, Cann and Genoa Rivers suggest high bed complexity at more upstream stations and lower complexity near main towns (EPA 1983). Chemical and physical water quality was generally high at all stations (EPA 1983).

The geomorphology and hydrology of these coastal inlets and estuaries are extremely variable (EPA 1983) and of considerable scientific interest (McRae-Williams et al. 1981). Wigan, Tamboon and Sydenham Inlets, and the Snowy Estuary, have statewide significance for hydrological and geomorphological studies. Several smaller inlets, particularly of the Red, Mueller and Benedore Rivers, have important potential as undisturbed reference catchments (McRae-Williams et al. 1981).

The coastal plains also contain a number of freshwater lakes. Eleven of these were studied by Timms (1973) who found two basic types. First, there are the floodplain lakes of the lower Snowy River. These are mostly the remains of former courses of the Snowy, but at least one, Cowell's Lagoon, was formed by deposits from the main river blocking a tributary. Those lakes in the Snowy's former watercourses can be markedly modified by flooding. Secondly, there are several sand-dune lakes. Lakes Elusive and Wau Wauka were formed in river valleys blocked by the inland movements of sand-dunes, but Lake Barracoota may once have been an arm of Mallacoota Inlet before being cut off from the estuary by sediment (Timms 1973). The three above lakes, plus the freshwater coastal lagoon, Dock Inlet, are accorded statewide significance by McRae-Williams et al. (1981).

Ladd (1978) described the probable history over the last 6,000 years of Lake Curlip on the Snowy flats. He also described aquatic and semi aquatic plant communities of this and other nearby shallow wetlands. Many of these have been destroyed by clearing and drainage over the last 120 years (Ladd, 1978).

Corrick and Norman (1980) classified and mapped wetlands important to waterbirds in the Snowy River and Gippsland Lakes catchments. They noted that the area contains almost as much wetland habitat as the whole New South Wales coast, but that about 36% has been eliminated or greatly modified.

### **Freshwater Invertebrates**

The potential scientific interest of the water bodies of East Gippsland is underscored by the present dearth of information on their invertebrate fauna. Very little research, of even an exploratory nature, has been published. Over 2,000 species of aquatic insects (the dominant group in Victoria streams) have so far been identified for Australia (Williams 1980), while around 250 species have been reported from two studies in East Gippsland. Timms (1973) collected about 50 species of bottom dwelling and littoral insects from three coastal freshwater lakes, and zooplankton from eleven such lakes. He also recorded about 30 species of Crustacea (out of a total of about 500 species described for Australia). EPA (1983), in a study using artificial substrata in lower and middle sections of five main streams, recognized at least 225 taxa of invertebrates, about 200 of which were larval insects, and 15 aquatic mites.

Scott & Co (1981) recorded 23 freshwater molluscs from Gippsland east of the Mitchell River, including 12 collected from various kinds of streams, as well as some basic habitat data. In addition, reference was made to 5 species of molluscs restricted to estuarine conditions. Most of the molluscs recorded by Scott & Co. (1981) occur east of the Snowy River (B.J. Smith, Museum of Victoria, December 1981, personal communication).

The work of Timms (1973) yielded at least 2 new species of littoral invertebrates; an ostracod and an isopod from the family Sphaeromidae, an essentially marine group. From Lake Barracoota, 3 out of a total of 14 benthic organisms were undescribed, and all 3 (an anthurid isopod, a sphaeromid isopod, and a polychaete worm, (*Boccardi* sp.) have marine affinities.

Most other species collected by Timms (1973) were widespread in eastern Australia. However, at least one, the gyrid beetle *Gyrinus convexiusculus*, is mainly distributed along the more northerly east coast, and the amphipod, *Austrochiltonia subtenuis*, is widely distributed in western Victoria and westwards. Most of the taxa recorded by EPA (1983) have been found in other Victorian streams, although several insect species do not appear to have been recorded outside East Gippsland. EPA (1983) noted relationships between physical factors, such as flow regime and bed structure, and the distribution and feeding behaviour of their 25 most common taxa. Only in the Cann River were human activities (in this case land clearing and agriculture) identified as having an adverse effect upon water quality or stream biota.

The Trichoptera is one of the most abundant and diverse groups of insects in most Australian streams, and East Gippsland appears to have a particularly rich trichopteran fauna (A. Neboiss, Museum of Victoria, December 1981, personal communication). There are four main components of this fauna.

- (i) Species widespread throughout temperate Australia, particularly in the south-east. This group includes the colorful genus *Anisocentropus*, and several species of the family Hydrobiosidae, especially associated with solid substrata and fast currents.
- (ii) East Coast forms, reaching the southerly and westerly limits of their distribution in East Gippsland. This group includes: *Ecnomina thinotes*, a species collected from Lake Barracoota, and elsewhere only from Fraser and North Stradbroke Islands in Queensland; *Orthotrichia tortuosa* Wells (1979), a recently described hydroptilid species collected from the Genoa River, occasional other forested streams in East Gippsland and coastal New South Wales, and the Carnavon Gorge in Queensland; and finally an undescribed species of *Diplectrona* sens. lat. (Family Hydropsychidae) which has been recorded only from the Cann River at Noorinbee and from Barrington Tops in New South Wales.
- (iii) Widespread, mainly inland forms, such as *Oecetis australis*, penetrating into East Gippsland along the warmer and drier valleys of the Snowy and Deddick Rivers.
- (iv) Species so far collected only from East Gippsland, and probably endemic to the region, with limited northward extension into coastal N.S.W. In the genus *Trienodes* along eight undescribed species have so far been collected only from East Gippsland.

A fifth small group is of species or genera mainly occurring in the mountain streams along Victoria's south coast. For instance *Stenopsychodes aureonigra* is a species found west of Mallacoota but belonging to an otherwise northerly genus. *Acanthotrichia bilamina* Wells (1982) is a rare and interesting species, representing a new genus in the family Hydroptilidae, and not fitting easily into



any of the above groups. It is described from the Genoa River at Wangarabell, and collected elsewhere only from the Gellibrand River in the Otway Ranges and from forested areas near Imbil in south-eastern Queensland.

The importance of northern species reaching their southern limit in East Gippsland is also apparent in the stoneflies (Plecoptera) (A. Neboiss, Museum of Victoria, December 1981, personal communication). A similar pattern is obvious in terrestrial butterflies, one of the few insect groups collected regularly in East Gippsland (Crosby 1951, 1963; Burns 1947, 1960). Several other groups, both terrestrial and aquatic, can be expected to show the same pattern.

Recent, as yet unpublished work on the taxonomy and distribution of freshwater crayfish (Parastacidae) has identified a number of new species, and species endemic to East Gippsland. Of four species of *Euastacus* occurring in the area, two are yet to be described, and two are only found in East Gippsland and small adjacent parts of New South Wales (G. Morgan, Museum of Victoria, May 1984, personal communication). The widespread and common genus *Engaeus* is also represented in East Gippsland by four species, of which three are endemic and two yet to be described (P. Horwitz, Zoology Department, University of Tasmania, May 1984, personal communication).

Although little is known about the ecology of particular members of the invertebrate fauna of East Gippsland streams, a number of generalisations can be made.

- (i) Most lotic species are adapted to solid substrata. This applies even in streams with naturally sandy beds. The relatively unstable, sandy portions of stream-beds harbour few specialist species. Many species normally associated with stony substrata still occur in sandy streams but are found mainly along the banks, on snags, logs and submerged plants (Morse *et. al.* 1980).
- (ii) partly as a result of (i) above, and partly because of greater microhabitat diversity, the fauna of cobble bed streams is usually more diverse than that of sandy streams (Hynes 1970; Metzeling *et. al.* 1984; EPA 1983).
- (iii) The fauna of a natural stream alters in a gradual manner from source to mouth along with the gradients of various physical and chemical factors (eg. Malipatil and Blyth, 1982; Vannote *et al.* 1980). However, many species are found mainly in particular stream stretches. For instance, a number of stoneflies, particularly from the family Eutheniidae, are restricted to cool stony mountain streams, while some dragonflies and damselflies (Odonata) are more common in warmer and more sluggish lowland streams.
- (iv) many montane species of caddis flies are restricted to first and second order streams, and are known to be particularly susceptible to increased sediment loads (A. Neboiss, Museum of Victoria, February 1984, personal communication).
- (v) Cool, stony upland streams of intermediate size generally support a more diverse fauna than either very small headwater streams or larger lowland streams. These small stony streams may be at particular risk from any sedimentation resulting from intensive forestry practices.



The distribution and ecology of the benthic fauna of East Gippsland estuaries is essentially unknown. The only published report of which we are aware (EPA 1983) recognized 90 taxa with marine affinities, including 37 species of Polychaeta, 24 of Crustacea and 19 of Mollusca.

During that study autumn/winter flooding appeared to reduced species richness of the estuarine fauna at all sites except those with the greatest marine influence.

Numbers of individuals and species richness were uncorrelated with sediment type, but particular groups of taxa were selectively associated with either sandy or muddy substrata. The dominant taxa and their preferred habitats resembled in main features those reported for other estuaries along the east coast of Australia (EPA 1983). Little evidence of adverse effects of human activities upon the estuaries, either for physical and chemical factors, or for biota, was reported by the EPA study. The only exception to this was evidence of increasing infilling of Tamboon Inlet resulting from agricultural activity and consequent bank erosion (EPA 1983).

### Fishes

Although there are few published data on the fishes of East Gippsland, surveys of the Snowy River and the rivers and estuaries of Croajingolong National Park have recently been undertaken (Tunbridge 1983) and much distributional data have been gathered during research for a recent book on freshwater fishes of Victoria (Cadwallader and Backhouse 1983). Nevertheless, large portions of the aquatic habitat have yet to be adequately surveyed and additional species to those recorded here will almost certainly be found.

The fishes of East Gippsland form part of a distinctive southern group of fishes found in Tasmania and coastal Victoria which extends north into southern New South Wales (McDowall 1981). Characteristic fish include several galaxiids (*Galaxias* spp.), the short-headed lamprey (*mordacia mordax*), smelts (*Retropinna* spp.), Australian grayling (*Prototroctes maraena*), freshwater blackfish (*Gadopsis marmoratus*) and tupong (*Pseudaphritis bursinus*). Many short-headed lamprey, Australian grayling, tupong and galaxiids have regular marine life history phases.

Fifty-three species have been recorded from freshwater and estuarine locations in East Gippsland. In Table 1 they have been grouped according to the particular type of life cycle they exhibit; many species cannot be conveniently classified as either freshwater or estuarine but utilize both environments. A question mark next to a particular fish indicates that the life cycle is poorly understood and the grouping thus uncertain.

Species in group 1 usually spend their entire life cycle in fresh water. Three are exotic to Australian waters; carp, *Cyprinus carpio*, brown trout, *Salmo trutta*, and rainbow trout, *Salmo gairdneri*. Carp occur in the lower reaches of the Snowy River and brown and rainbow trout in the upper reaches of the Snowy, Cann and Thurra Rivers. Brown and rainbow trout most commonly occur in cool, well-oxygenated waters and require flowing water and gravel substrata for reproduction. They feed on aquatic and terrestrial insects (Tilzey 1977). Carp

TABLE 1

Fish species recorded from fresh water and estuarine localities in East Gippsland. Compiled from Tunbridge (1983), Cadwallader and Backhouse (1983) and unpublished Fisheries and Wildlife records.

## GROUP 1. Entirely freshwater

|   |                             |                      |                |
|---|-----------------------------|----------------------|----------------|
|   | <i>Galaxias olidus</i>      | mountain galaxias    |                |
|   | <i>Nannoperca australis</i> | southern pygmy perch |                |
| E | <i>Gadopsis marmoratus</i>  | freshwater blackfish |                |
|   | <i>Salmo trutta</i>         | brown trout          |                |
| * | <i>Salmo gairdneri</i>      | rainbow trout        | exotic species |
|   | <i>Cyprinus carpio</i>      | European carp        |                |

## GROUP 2. Spawn in fresh water but part of life cycle in sea or estuary

|   |                               |                      |
|---|-------------------------------|----------------------|
| C | <i>Galaxias truttaceus</i>    | spotted galaxias     |
| C | <i>Galaxias brevipinnis</i>   | climbing galaxias    |
| ? | <i>Retropinna semoni</i>      | Australian smelt     |
| C | <i>Gobiomorphus australis</i> | striped gudgeon      |
|   | <i>Philypnodon grandiceps</i> | big-headed gudgeon   |
| B | <i>Prototroctes maraena</i>   | Australian grayling  |
|   | <i>Mordacia mordax</i>        | short-headed lamprey |

## GROUP 3. Spawn in sea or estuary but part of life cycle in fresh water

|    |                               |                    |
|----|-------------------------------|--------------------|
|    | <i>Galaxias maculatus</i>     | common galaxias    |
|    | <i>Pseudaphritis bursinus</i> | tipong             |
|    | <i>Anguilla australis</i>     | short-finned eel   |
|    | <i>Anguilla reinhardtii</i>   | long-finned eel    |
| C? | <i>Potamalosa richmondia</i>  | freshwater herring |

## GROUP 4. Estuarine species which invade fresh water

|   |                                |                         |
|---|--------------------------------|-------------------------|
|   | <i>Favonigobius tamarensis</i> | Tamar River goby        |
|   | <i>Pseudogobius olorum</i>     | Swan River goby         |
|   | <i>Arenigobius bifrenatus</i>  | bridled goby            |
|   | <i>Atherinosoma microstoma</i> | small-mouthed hardyhead |
|   | <i>Macquaria colonorum</i>     | estuary perch           |
| C | <i>Macquaria novemaculeata</i> | Australian bass         |
|   | <i>Acanthopagrus australis</i> | yellow-fin bream        |
|   | <i>Acanthopagrus butcheri</i>  | black bream             |
|   | <i>Girella tricuspidata</i>    | luderick                |

|                                  |                |
|----------------------------------|----------------|
| <i>Mugil cephalus</i>            | sea mullet     |
| <i>Platycephalus fuscus</i>      | dusky flathead |
| <i>Argyrosomus hololepidotus</i> | mullo way      |
| <i>Rhombosargus sarba</i>        | tar whine      |

**GROUP 5. Shallow water marine species common in estuaries but do not invade fresh water**

|                                |                          |
|--------------------------------|--------------------------|
| <i>Hyporhamphus ardelio</i>    | river garfish            |
| <i>Hyperlophus vittatus</i>    | sandy sprat              |
| <i>Spratelloides robustus</i>  | blue sprat               |
| <i>Aldrichetta forsteri</i>    | yellow-eyed mullet       |
| <i>Myxus elongatus</i>         | sand mullet              |
| <i>Muraenichthys breviceps</i> | short-headed worm eel    |
| <i>Allomycterus pilantus</i>   | porcupine fish           |
| <i>Arripis georgianus</i>      | tommy rough              |
| <i>Arripis trutta</i>          | Australian salmon        |
| <i>Aseraggodes haackeanus</i>  | southern sole            |
| <i>Chrysophrys auratus</i>     | snapper                  |
| <i>Tetractenos glaber</i>      | smooth toadfish          |
| <i>Gymnapistes marmoratus</i>  | South Australian cobber  |
| <i>Hemiramphus melanichir</i>  | South Australian garfish |
| <i>Parika scaber</i>           | velvet leatherjacket     |
| <i>Pomatomus saltarix</i>      | tailor                   |
| <i>Paratrigla vanessa</i>      | butterfly gurnard        |
| <i>Rhombosolea tapirina</i>    | greenback flounder       |
| <i>Sillaginodes punctata</i>   | spotted whiting          |
| <i>Stigmatopora argus</i>      | spotted pipefish         |
| <i>Pseudocaranax dentax</i>    | trevally                 |
| <i>Pterygotrigla polymmata</i> | sharp-beaked gurnard     |

? membership of group uncertain

B vulnerable      C restricted/rare      E requiring monitoring

Conservation categories based on Ahern (1982) and classification of species after recommendations of the Australian Society of Fish Biology (Cadwallader, et al. 1984).

\* Sea run populations may occur



are generally found in more gently flowing backwaters where they feed by sucking mud from the bottom and filtering out food items; spawning occurs in spring and summer when eggs are laid amongst aquatic plants (McDowall and Shearer 1980).

Controversy exists as to the effects of exotic species on the native fauna of Australia. It has been suggested that carp may create serious water turbidity problems due to their mode of feeding (McDowall and Shearer 1980) but recent research (Hume, Fletcher and Morison 1983) has indicated that, for several localities in Victoria, the presence of carp has not increased turbidities. There is growing evidence to suggest that brown and rainbow trout have deleteriously affected the distribution of the mountain galaxias, *Galaxias olidus* (Jackson 1981).

Compared to other areas of Victoria, East Gippsland contains a small number of exotic species, whose distributions are limited. It is unlikely that the native fauna has been seriously affected, with the possible exception of the mountain galaxias.

Only three native species complete their entire life cycle in fresh water; southern pigmy perch, *Nannoperca australis*, freshwater blackfish and the mountain galaxias. Southern pigmy perch have been recorded from the Betka and Red Rivers where they frequent weedy, slow-moving backwaters and feed on aquatic invertebrates. They breed in spring when the eggs are randomly scattered over the river-bed. Freshwater blackfish have been recorded from the Suggan Buggan and Deddick Rivers, both tributaries of the Snowy. The species generally frequent the slower-flowing stretches of rivers having abundant cover. Spawning occurs in late autumn and early spring when eggs are deposited inside submerged hollow logs (Jackson 1978). They feed on a wide range of aquatic and terrestrial invertebrates. The mountain galaxias has been recorded only from the Suggan Buggan River. It is primarily a small stream species inhabiting gravel-bottomed, well shaded stretches (McDowall 1980). The breeding biology of the mountain galaxias is unknown but eggs are probably laid in the gravel. It feeds on a variety of terrestrial and aquatic insects. Mountain galaxias are probably more widely distributed in East Gippsland than present knowledge indicates as many small tributaries have not been adequately sampled.

Fishes in group 2 spawn in fresh water but spend part of their life cycle in estuaries or at sea. Most spend the majority of their life in freshwater with only the juvenile stages entering brackish waters. The Australian grayling has been the subject of concern by conservationists in recent years. Lake (1971) considered it to be the Australian freshwater fish most seriously threatened with extinction but it was later regarded as rare (McDowall 1976). A meeting of Victorian members of the Australian Society of Fish Biology, convened in November 1982 to consider the status of native freshwater fish species (Cadwallader *et. al.* 1984), placed the Australian grayling in category B, vulnerable (Ahern 1982).

Recently Bell *et. al.* (1981) have shown that although the limits of the range of the Australian grayling have been substantially reduced, a number of populations still exist in south-eastern Australia. Despite recent work, (Berra 1982; Berra and Cadwallader 1983), aspects of the biology of Australian grayling are still poorly understood. It spawns in fresh water, in clear, gravel-bottomed streams after hatching the larvae are thought to drift downstream to the estuary where they remain for about six months before moving upstream (Bishop and Bell 1978). Whether or not they spawn in all rivers within their range is not known; they may spawn in only a few with the larvae then being



dispersed to other rivers. Until we have a greater knowledge of their biology it is essential to protect known populations of Australian grayling. In East Gippsland they have been recorded from the Snowy, Thurra and Wingan Rivers (B.R. Turnbridge, Fisheries and Wildlife Division, Victoria, Personal Communication, 1981).

A contrasting life cycle is exhibited by the short-headed lamprey. This species migrates to sea about 3.5 years after hatching and spends most of its adult life parasitic on marine fishes, only returning to fresh water to spawn and then die (Strahan 1980).

Most species in group 2 feed on aquatic and terrestrial invertebrates. However, the Australian grayling appears to be omnivorous, feeding on both aquatic invertebrates and on algae growing on rocks (Bishop and Bell 1978). The short headed lamprey filter-feeds on microscopic algae during its period in fresh water (Strahan 1980).

The five species in group 3 spawn in estuaries or at sea but spend part of their life in fresh water. The common galaxias, *Galaxias maculatus* occurs in the lower reaches of many rivers in East Gippsland. Mature adults migrate to estuaries during autumn, and their eggs are deposited amongst aquatic vegetation during a spring tide. The eggs hatch when they are submerged by the next spring tide. The larvae spend the winter in the estuary before migrating to fresh water as 'whitebait'. Common galaxias may, however, complete their entire life cycle in fresh water, and landlocked populations have been reported in Victoria (Pollard 1971). Timms (1973) has caught common galaxias in a landlocked situation in Lake Elusive.

The short-finned eel, *Anguilla australis*, and the long-finned eel, *Anguilla reinhardtii*, are both common in East Gippsland rivers. Adults of both species are believed to spawn somewhere in the Coral Sea off northern Queensland, in waters deeper than 350 metres. The larvae (leptocephali) are planktonic and are carried southward by the East Australian Current. They migrate into fresh water as glass eels (Beumer and Harrington 1980).

All species in group 3 feed on aquatic and terrestrial invertebrates.

The 13 species in group 4 are predominantly estuarine fishes which invade the fresh water environment. Some eg., Mulloway, *Argyrosomus hololepidotus*, and Australian bass, *Macquaria novemaculeata*, move long distances upstream, whereas species such as yellow-fin bream, *Acanthopagrus australis*, rarely occur in fresh water.

In most cases spawning takes place in the estuaries but some species, such as the sea mullet, *Mugil cephalus*, go to sea to spawn, making extensive migrations up and down the coast. Their feeding habits vary. Estuary perch, *Macquaria colonorum*, Australian bass and small-mouthed hardyhead *Atherinosoma microstoma* feed on aquatic invertebrates, whereas others such as luderick, *Girella tricuspidata*, feed on algae.

The 22 species in group 5 are all shallow-water marine species, commonly occurring in estuaries but not in fresh water. They include several important angling species such as yellow-eyed mullet, *Aldrichetta forsteri* and trevally, *Pseudocaranx dentex*. Most spend the majority of their life in the estuaries. Spawning usually takes place in the open sea or near the mouths of estuaries with the eggs and larvae drifting inshore. Species such as the river garfish, *Hyporhamphus ardelio*, are true estuarine species, living their whole life in the

estuary. In contrast, the snapper, *Chrysophrys auratus*, lives mainly at sea but the juveniles spend the first part of their lives in the estuary. Feeding habits vary; the South Australian cobbler, *Gymnapistes marmoratus*, feeds on aquatic invertebrates whereas the South Australian Garfish, *Hemiramphus melanochir* feeds on sea grass.

### Land Management in Catchments of East Gippsland Streams

Few baseline studies of these streams have been conducted, although Macmillan (1984) investigated the conservation value of third order streams draining the plateau country around Bonang, Bendoc and Errinundra. Most of East Gippsland's larger streams rise in this or other areas of tall wet forest in the mountainous hinterland. Macmillan (1984) showed that of nineteen fully forested catchments, eight had more than 10% of their area subjected to clear felling. Only one of the streams investigated (Concordia Creek, within a drier forest type) had its catchment fully protected within a reserve.

About 90% of East Gippsland supporting tall wet forest is currently zoned to hardwood production (L.C.C., 1977), and for these forests clearfelling and burning are the standard logging and regeneration procedures. No monitoring of streams in clearfelled areas has been conducted in East Gippsland. However, limited studies have been carried out on small streams in southern New South Wales. On the basis of weekly measurements of turbidity, electrical conductivity and temperature, Cornish (1980) concluded that logging and roading had had little impact upon environmental conditions of Mumbulla Creek, near Bega. Richardson (in press), working on fish and invertebrates in the same creek, showed that construction, (followed by failure and reconstruction) of a causeway on a logging road caused an obvious blanketing of the substratum downstream for about nine months. In addition, she showed that drift rates of some invertebrates were correlated with turbidity readings, and that appreciable differences in the structure of benthic communities existed between sites upstream and downstream of the causeway.

Visual inspection by a volunteer stream survey group indicated that some streams in the Errinundra area show symptoms of sediment pollution apparently associated with clearfelled areas (Blyth 1984). Log and debris jams, accompanied by physical blanketing with sand and silt of previously cobble bed, were noted, as were qualitative differences in the particle composition of a stream bed upstream and downstream of a forest road. There appear to be three main potential sources of sediment for the streams described by Blyth (1984).

- (i) Clearing across headwater areas, including soaks, gullies and small streams (perhaps intermittent). This practice results in destruction of headwater streams and swamps, and may generate sediment loads to lower streams. In addition, because stream buffer strips are only excluded from logging along permanent streams, temporary tributaries are logged and so may act as fresh sources of sediment to the main stream.
- (ii) Inadequate buffer strips along streams. At some sites felled over 10 years ago, logging and burning or other disturbances have been carried virtually to the stream edge. At other sites where buffer strips have been marked, falling in of felled trees has destroyed much of the vegetation in buffer strips, and filled streams with logs and organic detritus.
- (iii) Unsatisfactory road construction or maintenance. Instances exist where runoff from disturbed slopes runs directly down to the road edge, and from there into streams. Plumes of sediment along the road verge, leading

to heavy sediment deposits at the stream edge, are often visible. Road disturbance, coupled with rain and inadequate road drainage would cause heavy sediment input to streams. Work throughout the world indicates that inadequate road construction is often the major source of stream sediment from forestry operations (Fredriksen 1970; Langford and O'Shaughnessy 1977; Melbourne Metropolitan Board of Works (MMBW) 1980).

A possible fourth source of sediment is the logging of excessively steep slopes, although no observations have been made on this point. However, operating prescriptions for East Gippsland note that 'Steep slopes generally over 30° on which the risk of soil erosion is high would not be harvested', (Forest Commission of Victoria, 1983). It is noted that on particularly unstable soils logging may be excluded from slopes of over 20°. These prescriptions contrast with the recommendation in MMBW (1980). 'To avoid the likelihood of large scale earth movements or widespread erosion, timber harvesting must be excluded from areas with slopes of 25° or greater, and from areas with more erodible soils'. MMBW (1980) warn that these recommendations cannot be applied to other catchments unless all conditions are shown to be similar to those in their experimental area. However, they also note that the soils for which their recommendations do apply were stable and resistant to erosion.

There is considerable evidence in the scientific literature (eg. Ellis 1936; Chutter 1969; Graynoth 1979), of the impact on fish and invertebrates of gross blanketing of cobble bed by sand and silt. Research on the Mitta Mitta River (Blyth 1980; Blyth *et. al.* 1984) and on the Thompson River (Davey *et. al.* 1982) has shown that even where total blanketing of the bed does not occur, alteration of the bed structure by deep penetration of fine material, and by coating of solid surfaces with silt/algal mats, can reduce invertebrate species richness and invertebrate biomass by 50% or more.

Platts and Magahan (1975) examined recovery in a sediment polluted mountain stream in Idaho. Restoration of surface particle composition to pre-pollution levels took at least nine years after cessation of forestry activities which generated the sediment. In cases where sediment blanketing is often combined with choking of the stream with logging debris, (examples of which over ten years old occur on the Errinundra Plateau), the time for surface scouring to occur is likely to be much greater. Removal of fine material which has filled spaces within the bed will be slower still at depths below about 10 cm.

It is now known that large populations of invertebrates live deep within the stream bed (Hynes, Williams and Williams 1976; Pugsley and Hynes 1983). It is possible that filling of spaces in the riverbed may have a critical effect upon seasonal movement and life cycle patterns, so that long-term reduction in diversity and abundance of stream-bed fauna results.

Aquatic invertebrates form a major component of the diets of many East Gippsland fishes. Any reduction in abundance or diversity of invertebrates may adversely affect these fishes.

Overseas information indicates that sedimentation drastically affects fish reproduction by reducing survival rates of eggs and larvae (Chapman 1962). Sedimentation alters gravel permeability and thus intragravel water velocities (Pollard 1955). Dissolved oxygen is likely to decrease as permeability and velocity decrease because of less interchange of surface and groundwater, and



because of biochemical oxygen demand in the gravel. Those fishes which deposit their eggs in gravel substrata and require running water and high oxygen levels for egg incubation are adversely affected. Additionally, sedimentation tends to fill the spaces around cobbles, pebbles and other bottom irregularities, reducing the amount of protective cover for larval fish (McCrimmon 1954).

Although research into the effect of sedimentation on fish reproduction has centered largely on salmonid species (salmons and trouts) it can be reasonably assumed that effects on other fishes which require clear, flowing streams and a gravel substratum for reproduction will be equally severe. The reproductive biology of many of East Gippsland's fishes is poorly understood, but species such as the Australian grayling (*Prototroctes maranena*) apparently require conditions similar to Salmonids for reproduction. The freshwater blackfish (*Gadopsis marmoratus*), which deposits its eggs in submerged hollow logs is also likely to be affected, both by the burial of many suitable spawning sites and, if spawning does take place, by the burial of eggs and of the larvae, which remain immobile inside the log for some 19 days after hatching (Jackson 1978). The whole question of the effects of sedimentation on the reproduction of Australian native fishes is in urgent need of detailed research.

Unless stream buffer zones are sufficiently wide to prevent the formation of log jams, these could form obstacles to fish migration. A very high proportion of East Gippsland's fishes move between estuarine and freshwater environments at some stage of their life cycles. Any barrier which impedes or prevents movements of these fishes will affect their populations. There is good evidence to suggest that barriers of various types have had an inhibitory effect on Australian bass populations in south-eastern Australia (J. Harris, University of New South Wales, personal communication, 1982). In a survey of eastern flowing streams between Fraser Island and Lakes Entrance, Harris (1981, 1983) found a total of 276 dams and weirs with an average of 13 barriers on each of 23 drainage systems surveyed. He considered that there is a major level of interference with the migration pathways of fish in the South-eastern coastal region of Australia. The only East Gippsland stream listed by Harris (1983) is the Snowy River. The Snowy catchment contains 5 dams ranging in height above waterlevel from 3 to 98 meters and 4 weirs ranging in height from 1 to 2 metre (Harris 1983). Log jams, together with accumulated sedimentation may be sufficient to form additional barriers. Improper placement of culverts in streams to form bridges during road construction may also form effective barriers. Absence of cover within culvert pipes may mean that fish moving upstream are exposed to excessive water velocities whilst moving through the pipe and fish are unable to climb up the free flow of water pouring from the projected end of a culvert (McDowall, Graynoth and Eldon 1977).

A second potential impact of clearfelling is the increase in temperature of small streams resulting from the loss of shade. Such an effect is well documented overseas (eg. Brown and Krygier 1967, 1970) and the resulting loss of invertebrate and fish species adapted to cool conditions is also clear (Graynoth 1979). There is evidence (eg. Graynoth 1979) that stream-side buffer zones effectively prevent such temperature changes. However, as previously noted, in East Gippsland buffer zones may be either absent or inadequate. There does not appear to have been any monitoring of the temperature of East Gippsland streams whose catchments are currently clearfelled.



Nothing is known about the amounts, if any, of extra sediment reaching estuaries as a result of intensive forestry operations. However rapid infilling by apparently biogenic sediment (mainly from agricultural areas) has been recorded in the Tamboon Inlet, East Gippsland (EPA 1983) and in other Australian estuaries (Bird 1968; Ellis and Kanamori 1977).

The dependence upon sea grass beds of penaeid prawn populations (Young 1978) and invertebrate diversity (Powis and Robinson 1980) has been shown in Australian estuaries. Thus, any extra unstable sediments and increased turbidity which have an adverse effect on sea grass beds (Orth 1977; Young 1978) will inevitably affect the invertebrate fauna.

The effects of forestry operations on estuarine fishes are not well documented either. However, increases in sedimentation can cause changes in the species composition by reducing light intensity, which affects feeding and predation.

Three lines of research are urgently needed on East Gippsland aquatic systems. First, what species do occur and what are the physical conditions upon which they depend for survival? Secondly, what are the actual effects, if any, upon the physical conditions (eg. bed structure) and on the benthic fauna of streams whose catchments have been clearfelled? Finally what management steps may be necessary to avoid damage to aquatic ecosystems?

Protection of water quality and aquatic biota can only be achieved by management which considers whole catchments (Hynes 1970, 1975; Cummins 1974, Vannote et al. 1980). With the exception of relatively limited areas reserved as water catchments around major towns, little recognition of this principle has been shown in land management in Victoria. Streams in agricultural areas have undergone immense changes, such as clearing of valleys and banks, and resulting inputs of nutrients, sediment and agricultural chemicals (Standing Consultative Committee on River Improvement, 1983). Most major rivers and many smaller creeks in mountainous areas have had their flow and temperature regimes modified by dam construction, while mining, construction activities, and intensive forestry practices have generated large sediment loads to many foothill streams. Thus, the streams of East Gippsland are likely to be important in the elucidation of ecological processes and limiting factors operating in relatively unmodified Victorian streams, particularly those of foothills and lower reaches.

## Conclusions

East Gippsland as a whole has considerable significance for freshwater biologists. First, the freshwater invertebrate fauna is almost totally unknown. What little work has been done suggests that many as yet unknown species will be found restricted to East Gippsland. Secondly, streams in the area, being relatively unmodified, can provide scientific references against which to judge the state of many other streams of coastal south-eastern Australia. Thirdly, because of its range of climate and habitat types, and its geographical position, East Gippsland would be expected to have an extremely diverse aquatic fauna. Work to date suggests that this is the case, and that the region is important as a transition area between different climatic zones, and harbours several different groups of species at the limit of their ranges.

East Gippsland contains no fish species not found elsewhere in Victoria or southern New South Wales, but the diversity of native species is high. Of the 36 species of native 'freshwater' fish listed by McDowall (1980) as occurring in coastal drainages in southern New South Wales and Victoria, 24 have been recorded in East Gippsland. Furthermore only three exotic species have been recorded and their distributions are limited. Exotic fishes, particularly brown and rainbow trout, are widespread in south eastern Australia. There are very few waters in which they do not occur and areas like East Gippsland are becoming increasingly rare.

The Croajingolong National Park is of particular significance. Extensive surveys of both freshwater and estuarine environments within the park have revealed 52 native species and no introduced fishes (Tunbridge 1983). The only other comparable area in Victoria is Wilsons Promontory, but there the rivers and estuaries are smaller and do not support the same diversity of species. It is essential that unique areas like Croajingolong National Park are protected. The catchments of its major rivers, the Cann, Thurra, Mueller, Wingan and Betka Rivers extend well beyond the boundaries of the park and must be protected. Finally, the fauna of Lake Barracoota is particularly interesting, having links with dune lakes much further north, as well as species with marine affinities.

Present forestry operations in East Gippsland may be creating changes which will decrease the diversity of both habitats and fauna as well as the aesthetic amenity of streams and estuaries in the area. Areas of Victoria which have been subject to intensive forestry practices for many years (eg. parts of the Otways, and the Murrindini catchment) now have streams whose beds are almost entirely sand. Base line information on these areas is inadequate to allow us to assess how much this is a natural phenomenon and how much is due to activities related to timber extraction. Detailed research on East Gippsland streams is required, both for wise management of these streams and for elucidation of past occurrences in streams throughout the state. Such research should examine the amount, grades, and final fate of erosion sediment from various logging operations, plus its effect on stream-bed structure and aquatic biota.

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